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PLUMBERS AND FITTERS' HANDBOOK

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PLUMBERS AND FITTERS' HANDBOOK

A CONVENIENT REFERENCE BOOK

FOR ALL PERSONS INTERESTED IN

Plumbing, Steam Heating, Hot-Air Heating,
Hot-Water Heating, Ventilation,
Gas-Fitting, Drainage,
and Sewerage

BY

INTERNATIONAL CORRESPONDENCE SCHOOLS,

SCRANTON, PA.

1st Edition, 45th Thousand, 6th Impression

SCRANTON, PA.

INTERNATIONAL TEXTBOOK COMPANY

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PREFACE

The growing demand for a book of reference devoted to the plumbing, heating, ventilating, and gas-fitting trades has induced the publication of the Plumbers and Fitters' Handbook, which is the first reference work of its kind, and will be found to contain more valuable information along the lines indicated by its title than any other book of its size yet published.

It has been the aim of the publishers to present to the public a handy reference work that is not only of a size convenient to carry in the coat or hip pocket—a pocketbook in reality as well as in name—but which also contains those rules, formulas, tables, etc.—together with explanations concerning them and practical examples illustrating their use,—which are most commonly needed by the master mechanics and journeymen of the various trades covered.

The publishers have not endeavored to produce a condensed encyclopedia of the art and practice of plumbing, heating, ventilation, and gas-fitting, but have striven to anticipate the daily wants of the user and to give him the information sought, in the manner best suited to his needs. The aim

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has been to meet the necessities not only of the mechanics in the trades mentioned, but also of all persons in any way interested in the design, construction, and maintenance of buildings and utilities pertaining thereto. In accomplishing this, the publishers have selected that rule, formula, or process which is, in their opinion, best adapted to the circumstances of the case, describing it fully, giving whenever possible full directions how and when to use it, and not mentioning other available methods when doing so would tend to confuse the reader. In other words, the selection has been made by the publishers instead of leaving it to the judgment of the reader.

The Plumbers and Fitters' Handbook will be found a valuable aid to plumbers, heating and ventilating engineers, steam fitters, gas-fitters, architects, contractors, builders, building and plumbing inspectors, sanitary and civil engineers, superintendents and owners of buildings, traveling salesmen and solicitors for supply houses, etc.

This handbook was prepared under the supervision of Mr. T. N. Thomson, Principal of the School of Plumbing, Heating, and Ventilation, assisted by the following members of our staff of textbook writers: Messrs. J. A. Grening, C. Wadsworth, L. H. Hall, and J. J. Cosgrove.

International Correspondence Schools,

February 1, 1905. Scranton, Pa.

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PLUMBERS AND FITTERS' HANDBOOK.

ARITHMETIC.

SIGNS USED IN CALCULATION.

$+$ *Plus*, indicates *addition;* thus, $10 + 5$ is 15.

$-$ *Minus*, indicates *subtraction;* thus, $10 - 5$ is 5.

$\times$ *Multiplied by*, indicates *multiplication;* thus, 10×5 is 50.

$\div$ *Divided by*, indicates *division;* thus, $10 \div 5$ is 2.

$=$ *Equal to*, indicates *equality;* thus, 12 in. $=$ 1 ft.

$( )$, $[ ]$, $\{ \}$, called *parenthesis*, *bracket*, and *brace*, respectively, have the same meaning, and signify that the operations indicated within them are to be performed first; or, if more than one is used, that indicated in the inner one is to be effected first. Thus, in the expression $5(7-2)$, the subtraction is to be made before multiplying by 5. Again, in the expression $\frac{1}{2}\left[a+\left(b-\frac{c}{4}\right)\right]$, the subtraction indicated within the parenthesis is made first; the remainder is added to a, and one-half the sum found.

——, called the *vinculum*, is used for the same purpose as the parenthesis, but chiefly in connection with the sign $\sqrt{}$; thus, $\sqrt{\quad}$.

. , called the *decimal point*, is placed in a number containing decimals, to fix the value of the number; thus, 12.5 is 12 and $\frac{5}{10}$; 1.25 is 1 and $\frac{25}{100}$; etc.

8^2 means that the number 8 is to be *squared;* thus, $8^2 = 8 \times 8 = 64$.

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8^3 means that the number 8 is to be *cubed;* thus, $8^3 = 8 \times 8 \times 8 = 512$.

$\sqrt{\ }$, called the *radical sign*, means that some root of the expression under it is to be found; if used without a small index figure, it means square root; thus, $\sqrt{64} = 8$.

$\sqrt[3]{\ }$ $\sqrt[4]{\ }$ mean that the *cube* or the *fourth* root is to be found, the index figure indicating the root; thus, $\sqrt[3]{27} = 3$.

: :: : means proportion; thus, 3 : 4 :: 6 : 8 is read *3 is to 4 as 6 is to 8.* Instead of the :: sign, the equality sign = is often substituted; thus, 3 : 4 = 6 : 8.

° ′ ″ mean degrees, minutes, and seconds; as, 60° 15′ 15″, which is read *60 degrees, 15 minutes, 15 seconds.*

′ ″ also mean feet and inches; thus, 7′ 6″ is read *7 feet 6 inches.*

π (read *pi*) means the ratio of the circumference of a circle to the diameter and = 3.1416.

Σ (read *sigma*) means *summation;* thus, $\Sigma(a + b)$ means that there are several values for both a and b, and that the sum of all is to be found.

FRACTIONS.

It is taken for granted that the reader knows how to perform the common operations of addition, subtraction, etc., where only whole numbers are used; but, when there are mixed or fractional numbers, a little refreshment of the memory may be desirable to some; hence, a little space is devoted to this elementary branch of arithmetic.

COMMON FRACTIONS.

The *numerator* of a fraction is the number above the bar; and the *denominator* is the number beneath it; thus, in the fraction $\frac{3}{4}$, 3 is the numerator and 4 is the denominator. Two or more fractions having the same denominator are said to have a *common* denominator. By "reducing fractions to a common denominator" is meant finding such a denominator as will contain each of the given denominators without a

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remainder, and multiplying each numerator by the number of times its denominator is contained in the common denominator. Thus, the fractions $\frac{1}{4}$, $\frac{7}{8}$, and $\frac{9}{16}$ have, as a common denominator, 16; then, $\frac{1}{4} = \frac{4}{16}$; $\frac{7}{8} = \frac{14}{16}$; $\frac{9}{16} = \frac{9}{16}$.

By "reducing a fraction to its lowest terms" is meant dividing both numerator and denominator by the greatest number that each will contain without a remainder; for example, in $\frac{14}{16}$, the greatest number that will thus divide 14 and 16 is 2; so that, $\frac{14 \div 2}{16 \div 2} = \frac{7}{8}$, which is $\frac{14}{16}$ reduced to the lowest terms.

A *mixed* number is one consisting of a whole number and a fraction, as $7\frac{1}{8}$.

An *improper* fraction is one in which the numerator is equal to, or greater than, the denominator, as $\frac{17}{8}$. This is reduced to a mixed number by dividing 17 by 8, giving $2\frac{1}{8}$. If the numerator is less than the denominator, the fraction is termed *proper*. A mixed number is reduced to a fraction by multiplying the whole number by the denominator, adding the numerator, and placing the sum over the denominator; thus, $1\frac{7}{8} = \frac{(1 \times 8) + 7}{8} = \frac{15}{8}$.

To add fractions or mixed numbers. If fractions only, reduce them to a common denominator, add partial results, and reduce sum to a whole or mixed number. If mixed numbers are to be added, add the sum of the fractions to that of the whole numbers; thus, $1\frac{7}{8} + 2\frac{1}{4} = (1 + 2) + (\frac{7}{8} + \frac{2}{8}) = 4\frac{1}{8}$.

To subtract two fractions or mixed numbers. If they are fractions only, reduce them to a common denominator, take less from greater, and reduce result; as, $\frac{7}{8}$ in. $- \frac{9}{16}$ in. $= \frac{14 - 9}{16}$ $= \frac{5}{16}$ in. If they are mixed numbers, subtract fractions and whole numbers separately, placing remainders beside one another; thus, $3\frac{7}{8}$ in. $- 2\frac{1}{4}$ in. $= (3 - 2) + (\frac{7}{8} - \frac{2}{8}) = 1\frac{5}{8}$ in. With fractions like the following, proceed as indicated: $3\frac{7}{16}$ in. $- 1\frac{13}{16}$ in. $= (2 + \frac{18}{16} + \frac{7}{16}) - 1\frac{13}{16} = 2\frac{25}{16} - 1\frac{13}{16} = 1\frac{12}{16} =$ $1\frac{3}{4}$ in.; 7 in. $- 4\frac{3}{4}$ in. $= (6 + \frac{4}{4}) - 4\frac{3}{4} = 2\frac{1}{4}$ in.

To multiply fractions. Multiply the numerators together, and likewise the denominators, and divide the former by th

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latter; thus, $\frac{1}{2}$ in. $\times \frac{3}{4}$ in. $\times \frac{5}{8}$ in. $= \frac{1 \times 3 \times 5}{2 \times 4 \times 8} = \frac{15}{64}$ cu. in. If mixed numbers are to be multiplied, reduce them to fractions, and proceed as above shown; thus, $1\frac{1}{2}$ in. $\times 3\frac{1}{4}$ in. $= \frac{3}{2} \times \frac{13}{4} = \frac{39}{8} = 4\frac{7}{8}$ sq. in.

To divide fractions. Invert the divisor (i. e., exchange places of numerator and denominator) and multiply the dividend by it, reducing the result, if necessary; thus, $\frac{7}{8} \div \frac{3}{4} = \frac{7}{8} \times \frac{4}{3} = \frac{28}{24} = \frac{7}{6} = 1\frac{1}{6}$. If there are mixed numbers, reduce them to fractions, and then divide as just shown; thus, $1\frac{5}{8} \div 3\frac{1}{4} = \frac{13}{8} \div \frac{13}{4}$, or $\frac{13}{8} \times \frac{4}{13} = \frac{52}{104} = \frac{1}{2}$.

DECIMAL FRACTIONS.

In decimals, whole numbers are divided into tenths, hundredths, etc.; thus, $\frac{1}{10}$ is written .1; .08 is read $\frac{8}{100}$, the value of the number being indicated by the position of the decimal point; that is, one figure after the decimal point is read as so many tenths; two figures as so many hundredths; etc. Moving the decimal point to the right multiplies the number by 10 for every place the point is moved; moving it to the left divides the number by 10 for every place the point is moved. Thus, in 125.78 (read 125 and $\frac{78}{100}$), if the decimal point is moved one place to the right, the result is 1,257.8, which is 10 times the first number; or, if the point is moved to the left one place, the result is 12.578 which is $\frac{1}{10}$ the first number, moving the point being equivalent to dividing 125.78 by 10.

Annexing a cipher to the right of a decimal does not change its value; but each cipher inserted between the decimal point and the decimal divides the decimal by 10; thus, in 125.078, the decimal part is $\frac{1}{10}$ of .78.

To add decimals. Place the numbers so that the decimal points are in a vertical line, and add in the ordinary way, placing the decimal point of the sum under the other points.

```
101.257
 12.965
 43.005
920.600
---------
1,077.827
```

To subtract decimals. Place the number to be subtracted with its decimal point under that of the other number, and subtract in the ordinary way.

```
917.678
482.710
---------
434.968
```

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To multiply decimals. Multiply in the ordinary way, and point off from the right of the result as many figures as there are figures to the right of the decimal points in *both* numbers multiplied; thus, in the example here given, there are three figures to the right of the points, and that many are pointed off in the result. If either number contains no decimal, point off as many places as are in the number that does.

```
 21.72
  34.1
 ----
  2172
 8688
 6516
 ------
740.652
```

If a result has not as many figures as the sum of the decimal places in the numbers multiplied, prefix enough ciphers before the figures to make up the required number of places, and place the decimal point before the ciphers. Thus, in .002 × .002, the product of 2 × 2 = 4; but there are three places in each number; hence, the product must have *six* places, and five ciphers must be prefixed to the 4, which gives .000004.

To divide decimals. Divide in the usual way. If the dividend has *more* decimal places than the divisor, point off, from the right of the quotient, the number of places in *excess*. If it has *less* than the divisor, annex as many ciphers to the decimal as are necessary to give the dividend as many places as there are in the divisor; the quotient will then have *no* decimal places. For example, $\frac{25.75}{2.5} = 10.3$; $\frac{82.5}{2.75} = \frac{82.50}{2.75} = 30$; $\frac{7.5}{2.5} = 3$.

To carry a division to any number of decimal places. Annex ciphers to the dividend, and divide, until the desired number of figures in the quotient is reached, which are pointed off as above shown. Thus, 36.5 ÷ 18.1 to three decimal places $= \frac{36.5000}{18.1} = 2.016+$. (The sign + thus placed after a number indicates that the exact result would be more than the one given if the division were carried further.)

To reduce a decimal to a common fraction. Place the decimal as the numerator; and for the denominator put 1 with as many ciphers as there are figures to the right of the decimal point; thus, .375 has three figures to the right of the point; hence, .375 in. = $\frac{375}{1000}$ = $\frac{3}{8}$ in.

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To reduce a common fraction to a decimal. Divide the numerator by the denominator, and point off as many places as there have been ciphers annexed; thus, $\frac{3}{16}$ in. = 3.0000 ÷ 16 = .1875 in.

DUODECIMALS.

The duodecimal system of numerals is that in which the base is 12, instead of 10, as in the common decimal system. As a method of calculation it has fallen into almost entire disuse, and it is only in calculation of areas that duodecimals are now used. When the work becomes familiar, the work is practically as rapid as by using feet and decimals, and has the advantage of being absolutely accurate, which the decimal system is not, as inches cannot be expressed exactly in decimals of a foot. The principles upon which the work is based are as follows: When feet are multiplied by feet, or inches by inches, the product is, of course, square feet or square inches, respectively; but, when feet are multiplied by inches, or vice versa, the results may, for want of a better name, be termed *parts* (although this name was given originally to the 144th part of a square foot). Suppose a square foot to be divided into 144 sq. in.; then a strip 12 in., or 1 ft., long, and 1 in. wide will correspond to 1 part. A strip 5 ft. long and 7 in. wide will contain 7×5, or 35 parts, which, divided by 12 (parts to a square foot), equals 2 sq. ft. and 11 parts, or 2 sq. ft. + (11 × 12) sq. in. Square inches may be reduced to parts by dividing by 12; thus, 54 sq. in. = 4 parts 6 sq. in. To illustrate these principles, let it be required to find the area of a room 18 ft. 10 in. long, and 16 ft. 7 in. wide. Place feet under feet, and inches under inches, thus:

Feet.	*Inches.*	
18	10	
16	7	
301	4	
10	11	10
312 sq. ft.	3 parts	10 sq. in.,

or, 312 sq. ft. 46 sq. in.

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Begin by multiplying 10 in. by 16 ft., which equals 160 parts, or 13 sq. ft. 4 parts. Place the 4 parts in the inches column, and carry the 13 sq. ft. Then 18 ft. $\times$ 16 ft. = 288 sq. ft. + 13 sq. ft. = 301 sq. ft. Next, multiply 10 in. by 7 in. = 70 sq. in., or 5 parts 10 sq. in. Set the 10 sq. in. to the right of the column of parts, as shown. Then, 18 ft. $\times$ 7 in. = 126 parts + 5 parts carried = 131 parts; dividing by 12, 131 parts = 10 sq. ft. 11 parts. Set these down in the proper columns and add, beginning at the right; 4 parts + 11 parts = 1 sq. ft. 3 parts. Expressed in square feet and square inches, the result is 312 sq. ft. 46 sq. in., which can be verified by reducing the given numbers to inches, multiplying them, and dividing by 144.

INVOLUTION.

Involution is the process of multiplying a number by itself one or more times, the product obtained being called a certain *power* of the number. If the number is multiplied by itself, the result is called the *square* of the number; thus, 9 is the square of 3, since $3 \times 3 = 9$. If the square of a number is multiplied by the number, the result is called the *cube* of the number; thus, 27 is the cube of 3, since $3 \times 3 \times 3 = 27$. The power to which a number is to be raised is indicated by a small figure, called an *exponent*, placed to the right and a little above the number; thus, 7^2 means that 7 is to be squared; 27^3 means that 27 is to be cubed, etc.

The operations of involution present no difficulty, as nothing but multiplication is involved, the number of times the number is to be taken as a factor being shown by the exponent.

If the number is a fraction, raise both numerator and denominator to the power indicated.

A valuable little rule to memorize for finding the square of a mixed number in which the fraction is $\frac{1}{2}$, as $3\frac{1}{2}$, $10\frac{1}{2}$, etc., is as follows: *Multiply the next less whole number by the next greater, and add* $\frac{1}{4}$. For example, the square of $6\frac{1}{2}$ is 6 (the next less number) $\times$ 7 (the next greater) + $\frac{1}{4}$ = $42\frac{1}{4}$; $(19\frac{1}{2})^2 = 19 \times 20 + \frac{1}{4} = 380\frac{1}{4}$; $(8\frac{1}{2})^2 = 8 \times 9 + \frac{1}{4} = 72\frac{1}{4}$; etc.

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INVOLUTION AND EVOLUTION TABLE.

By means of the following table the square, cube, square root, cube root, and reciprocal of any number may be obtained correct always to five significant figures, and in the majority of cases correct to six significant figures.

In any number, the figures beginning with the first digit* at the left and ending with the last digit at the right, are called the *significant figures* of the number. Thus, the number 405,800 has the four significant figures 4, 0, 5, 8; and the number .000090067 has the five significant figures 9, 0, 0, 6, and 7.

The part of a number consisting of its significant figures is called the *significant part* of the number. Thus, in the number 28,070, the significant part is 2807; in the number .00812, the significant part is 812; and in the number 170.3, the significant part is 1703.

In speaking of the significant figures or of the significant part of a number, the figures are considered, in their proper order, from the first digit at the left to the last digit at the right, but no attention is paid to the position of the decimal point. Hence, *all numbers that differ only in the position of the decimal point have the same significant part.* For example, .002103, 21.03, 21,030, and 210,300 have the same significant figures 2, 1, 0, and 3, and the same significant part 2103.

The *integral part* of a number is the part to the left of the decimal point.

It will be more convenient to explain first how to use the table for finding square and cube roots.

SQUARE ROOT.

First point off the given number into periods of two figures each, beginning with the decimal point and proceeding to the left and right. The following numbers are thus pointed off: 12703, 1′27′03; 12.703, 12.70′30; 220000, 22′00′00; .000442, .00′04′42.

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* A cipher is not a digit.

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Having pointed off the number, move the decimal point so that it will fall between the first and second periods of the significant part of the number. In the above numbers, the decimal point will be placed thus: 1.2703, 12.703, 22, 4.42.

If the number has but three (or less) significant figures, find the significant part of the number in the column headed n; the square root will be found in the column headed $\sqrt{n}$ or $\sqrt{10n}$, according to whether the part to the left of the decimal point contains one figure or two figures. Thus, $\sqrt{4.42} = 2.1024$, and $\sqrt{22} = \sqrt{10 \times 2.20} = 4.6904$. The decimal point is located in all cases by reference to the original number after pointing off into periods.

There will be as many figures in the root preceding the decimal point as there are periods preceding the decimal point in the given number; if the number is entirely decimal, the root is entirely decimal, and there will be as many ciphers following the decimal point in the root as there are cipher periods following the decimal point in the given number.

Applying this rule, $\sqrt{220000} = 469.04$ and $\sqrt{.000442} = .021024$.

The operation when the given number has more than three significant figures is best explained by an example.

EXAMPLE.—(*a*) $\sqrt{3.1416} = ?$ (*b*) $\sqrt{2342.9} = ?$

SOLUTION.—(*a*) Since the first period contains but one figure, there is no need of moving the decimal point. Look in the column headed n^2 and find two consecutive numbers, one a little greater and the other a little less than the given number; in the present case, $3.1684 = 1.78^2$ and $3.1329 = 1.77^2$. The first three figures of the root are therefore 177. Find the difference between the two numbers between which the given number falls, and the difference between the smaller number and the given number; divide the second difference by the first difference, carrying the quotient to three decimal places and increasing the second figure by 1 if the third is 5 or a greater digit. The two figures of the quotient thus determined will be the fourth and fifth figures of the root. In the present example, dropping decimal points in the remainders, $3.1684 - 3.1329 = 355$, the first difference:

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3.1416 − 3.1329 = 87, the second difference; 87 ÷ 355 = .245+, or .25. Hence, $\sqrt{3.1416} = 1.7725$.

(*b*) $\sqrt{2342.9} = ?$ Pointing off into periods we get 23′42.90; moving the decimal point we get 23 4290; the first three figures of the root are 484; the first difference is 23.5225 − 23.4256 = 969; the second difference is 23.4290 − 23.4256 = 34; 34 ÷ 969 = .035+, or .04. Hence, $\sqrt{2342.9} = 48.404$.

CUBE ROOT.

The cube root of a number is found in the same manner as the square root, except the given number is pointed off into periods of three figures each. The following numbers would be pointed off thus: 3141.6, 3′141.6; 67296428, 67′296′428; 601426.314, 601′426.314; .0000000217, .000′000′021′700.

Having pointed off, move the decimal point so that it will fall between the first and second periods of the significant part of the number, as in square root. In the above numbers the decimal point will be placed thus: 3.1416, 67.296428, 601.426314, and 21.7.

If the given number has but three (or less) significant figures, find the significant part of the number in the column headed n; the cube root will be found in the column headed $\sqrt[3]{n}$, $\sqrt[3]{10n}$, or $\sqrt[3]{100n}$, according to whether one, two, or three figures precede the decimal point after it has been moved. Thus, the cube root of 21.7 will be found opposite 2.17, in column headed $\sqrt[3]{10n}$, while the cube root of 2.17 would be found in the column headed $\sqrt[3]{n}$, and the cube root of 217 in the column headed $\sqrt[3]{100n}$, all on the same line. If the given number contains more than three significant figures, proceed exactly as described for square root except that the column headed n^3 is used.

EXAMPLE.—(*a*) $\sqrt[3]{.0000062417} = ?$ (*b*) $\sqrt[3]{50932676} = ?$

SOLUTION.—(*a*) Pointing off into periods, we get 000′006′241′700; moving the decimal point, we get 6.2417. The number falls between 6.22950 = 1.84^3 and 6.33163 = 1.85^3; the first difference = 10213; the second difference is

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6.24170 − 6.22950 = 1220; 1220 ÷ 10213 = .119+, or .12, the fourth and fifth figures of the root. The decimal point is located by the rule previously given; hence, $\sqrt[3]{.0000062417} = .018412$.

(*b*) $\sqrt[3]{50932676} = ?$ As the number contains more than six significant figures, reduce it to six significant figures by replacing all after the sixth figure with ciphers, increasing the sixth figure by 1 when the seventh is 5 or a greater digit. In other words, the first five figures of $\sqrt[3]{50932700}$ and of $\sqrt[3]{50932676}$ are the same. Pointing off into periods, we get 50′932′700; moving the decimal point, we get 50.9327, which falls between $50.6530 = 3.70^3$ and $51.0648 = 3.71^3$; the first difference is 4118; the second difference is 2797; 2797 ÷ 4118 = .679+, or .68. The integral part of the root evidently contains three figures; hence, $\sqrt[3]{50932676} = 370.68$, correct to five figures.

SQUARES AND CUBES.

If the given number contains but three (or less) significant figures, the square or cube is found in the column headed n^2 or n^3, opposite the given number in the column headed n. If the given number contains more than three significant figures, proceed in a manner similar to that described for extracting roots. To square a number, place the decimal point between the first and second significant figures and find in the column headed $\sqrt{n}$ or $\sqrt{10n}$ two consecutive numbers, one of which shall be a little greater and the other a little less than the given number. The remainder of the work is exactly as heretofore described. To locate the decimal point, employ the principle that the square of any number contains either twice as many figures as the number squared or twice as many less one. If the column headed $\sqrt{10n}$ is used, the square will contain twice as many figures, while if the column headed $\sqrt{n}$ is used, the square will contain twice as many figures as the number squared, less one. If the number contains an integral part, the principle is applied to the integral part only; if the number is wholly decimal, there will be twice as many ciphers following the

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decimal in the square or twice as many plus one as in the number squared, depending on whether $\sqrt{10n}$ or $\sqrt{n}$ column is used. For example, 273.42^2 will contain five figures in the integral part; 4516.2^2 will contain eight figures in the integral part, all after the fifth being denoted by ciphers; $.0029453^2$ will have five ciphers following the decimal point; $.052436^2$ will have two ciphers following the decimal point.

EXAMPLE.—(*a*) $273.42^2 = ?$ (*b*) $.052436^2 = ?$

SOLUTION.—(*a*) Placing the decimal point between the first and second significant figures, the result is 2.7342; this number occurs between $2.73313 = \sqrt{7.47}$ and $2.73496 = \sqrt{7.48}$ in the column headed $\sqrt{n}$. The first difference is 2.73496 — 2.73313 = 183; the second difference is 2.73420 — 2.73313 = 107; and 107 ÷ 183 = .584+, or .58. Hence, $273.42^2 = 74{,}758$, correct to five significant figures.

(*b*) Shifting the decimal point to between the first and second significant figures, we get the number 5.2436, which falls between $5.23450 = \sqrt{27.4}$ and $5.24404 = \sqrt{27.5}$. The first difference is 954; the second difference is 910; 910 ÷ 954 = .953+, or .95. Hence, $.052436^2 = .0027495$, to five significant figures.

A number is cubed in exactly the same manner, using the column headed $\sqrt[3]{n}$, $\sqrt[3]{10n}$, or $\sqrt[3]{100n}$, according to whether the first period of the significant part of the number contains one, two, or three figures, respectively. If the number contains an integral part, the number of figures in the integral part of the cube will be three times as many as in the given number if column headed $\sqrt[3]{100n}$ is used; it will be three times as many less 1 if the column headed $\sqrt[3]{10n}$ is used; and it will be three times as many less 2 if the column headed $\sqrt[3]{n}$ is used. If the given number is wholly decimal the cube will have either three times, three times plus one, or three times plus two, as many ciphers following the decimal as there are ciphers following the decimal point in the given number.

EXAMPLE.—(*a*) $129.684^3 = ?$ (*b*) $.76442^3 = ?$ (*c*) $.032425^3 = ?$

SOLUTION.—(*a*) Placing the decimal point between the

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first and second significant figures, the number 1.29684 is found between $1.29664 = \sqrt[3]{2.18}$ and $1.29862 = \sqrt[3]{2.19}$. The first difference is 198; the second difference is 20; and $20 \div 198 = .101+$, or .10. Hence, the first five significant figures are 21810; the number of figures in the integral part of the cube is $3 \times 3 - 2 = 7$; and $129.684^3 = 2{,}181{,}000$, correct to five significant figures.

(*b*) 7.64420 occurs between $7.64032 = \sqrt[3]{446}$ and $7.64603 = \sqrt[3]{447}$. The first difference is 571; the second difference is 388; and $388 \div 571 = .679+$, or .68. Hence, the first five significant figures are 44668; the number of ciphers following the decimal point is $3 \times 0 = 0$; and $.76442^3 = .44668$, correct to five significant figures.

(*c*) 3.2425 falls between $3.24278 = \sqrt[3]{34.1}$ and $3.23961 = \sqrt[3]{34.0}$. The first difference is 317; the second difference is 289; $289 \div 317 = .911+$, or .91. Hence, the first five significant figures are 34091; the number of ciphers following the decimal point is $3 \times 1 + 1 = 4$; and $.032425^3 = .000034091$, correct to five significant figures.

RECIPROCALS.

The reciprocal of a number is 1 divided by the number. By using reciprocals, division is changed into multiplication, since $a \div b = \frac{a}{b} = a \times \frac{1}{b}$. The table gives the reciprocals of all numbers expressed with three significant figures to six significant figures. By proceeding in a manner similar to that just described for powers and roots, the reciprocal of any number correct to five significant figures may be obtained. The decimal point in the result may be located as follows: If the given number has an integral part, the number of ciphers following the decimal point in the reciprocal will be one less than the number of figures in the integral part of the given number; and if the given number is entirely decimal, the number of figures in the integral part of the reciprocal will be one greater than the number of ciphers following the decimal point in the given number. For example, the reciprocal of 3370 = .000296736 and of .00348 = 287.356.

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When the number whose reciprocal is desired contains more than three significant figures, express the number to six significant figures (adding ciphers, if necessary, to make six figures) and find between what two numbers in the column headed $\frac{1}{n}$ the significant figures of the given number falls; then proceed exactly as previously described to determine the fourth and fifth figures.

EXAMPLE.— (*a*) The reciprocal of 379.426 =? (*b*) $\frac{1}{.0004692}$ = ?

SOLUTION. — (*a*) .379426 falls between .378788 = $\frac{1}{2.64}$ and .380228 = $\frac{1}{2.63}$. The first difference is 380228 — 378788 = 1440; the second difference is 380228 — 379426 = 802; 802 ÷ 1440 = .557, or .56. Hence, the first five significant figures are 26356, and the reciprocal of 379.426 is .0026356, to five significant figures.

(*b*) .469200 falls between .469484 = $\frac{1}{2.13}$ and .467290 = $\frac{1}{2.14}$. The first difference is 2194; the second difference is 284; 284 ÷ 2194 = .129+, or .13. Hence, $\frac{1}{.0004692}$ = 2131.3, correct to five significant figures.

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
1.01	1.0201	1.03030	1.00499	3.17805	1.00332	2.16159	4.65701	.990099
1.02	1.0404	1.06121	1.00995	3.19374	1.00662	2.16870	4.67233	.980392
1.03	1.0609	1.09273	1.01489	3.20936	1.00990	2.17577	4.68755	.970874
1.04	1.0816	1.12486	1.01980	3.22490	1.01316	2.18278	4.70267	.961539
1.05	1.1025	1.15763	1.02470	3.24037	1.01640	2.18976	4.71769	.952381
1.06	1.1236	1.19102	1.02956	3.25576	1.01961	2.19669	4.73262	.943396
1.07	1 1449	1.22504	1.03441	3.27109	1.02281	2.20358	4.74746	.934579
1.08	1.1664	1.25971	1.03923	3.28634	1.02599	2.21042	4.76220	.925926
1.09	1.1881	1.29503	1.04403	3.30151	1.02914	2.21722	4.77686	.917431
1.10	1.2100	1.33100	1.04881	3.31662	1.03228	2.22398	4.79142	.909091
1.11	1.2321	1 36763	1.05357	3.33167	1.03540	2.23070	4.80590	.900901
1.12	1.2544	1.40493	1.05830	3.34664	1.03850	2.23738	4.82028	.892857
1.13	1.2769	1.44290	1.06301	3.36155	1.04158	2.24402	4.83459	.884956
1.14	1.2996	1.48154	1.06771	3.37639	1.04464	2.25062	4.84881	.877193
1.15	1.3225	1.52088	1.07238	3.39116	1.04769	2.25718	4.86294	.869565
1.16	1.3456	1.56090	1.07703	3.40588	1.05072	2.26370	4.87700	.862069
1.17	1.3689	1.60161	1.08167	3.42053	1.05373	2.27019	4.89097	.854701
1.18	1.3924	1.64303	1.08628	3.43511	1.05672	2.27664	4.90487	.847458
1.19	1.4161	1.68516	1.09087	3.44964	1.05970	2.28305	4.91868	.840336
1.20	1.4400	1.72800	1.09545	3.46410	1.06266	2.28943	4.93242	.833333
1.21	1.4641	1.77156	1.10000	3.47851	1.06560	2.29577	4.94609	.826446
1.22	1.4884	1.81585	1.10454	3.49285	1.06853	2.30208	4.95968	.819672
1.23	1.5129	1.86087	1.10905	3.50714	1.07144	2.30835	4.97319	.813008
1.24	1.5376	1.90662	1.11355	3.52136	1.07434	2.31459	4.98663	.806452
1.25	1.5625	1.95313	1.11803	3.53553	1.07722	2.32080	5.00000	.800000
1.26	1.5876	2.00038	1.12250	3.54965	1.08008	2.32697	5.01330	.793651
1.27	1.6129	2.04838	1.12694	3.56371	1.08293	2.33310	5.02653	.787402
1.28	1.6384	2.09715	1.13137	3.57771	1.08577	2.33921	5.03968	.781250
1.29	1.6641	2.14669	1.13578	3.59166	1.08859	2.34529	5.05277	.775194
1.30	1.6900	2.19700	1.14018	3.60555	1.09139	2.35134	5.06580	.769231
1.31	1.7161	2.24809	1.14455	3.61939	1.09418	2.35735	5.07875	.763359
1.32	1.7424	2.29997	1.14891	3.63318	1.09696	2.36333	5.09164	.757576
1.33	1.7689	2.35264	1.15326	3.64692	1.09972	2.36928	5.10447	.751880
1.34	1.7956	2.40610	1.15758	3.66060	1.10247	2.37521	5.11723	.746269
1.35	1.8225	2.46038	1.16190	3.67423	1.10521	2.38110	5.12993	.740741
1.36	1.8496	2.51546	1.16619	3.68782	1.10793	2.38696	5.14256	.735294
1.37	1.8769	2.57135	1.17047	3.70135	1.11064	2.39280	5.15514	.729927
1.38	1.9044	2.62807	1.17473	3.71484	1.11334	2.39861	5.16765	.724638
1.39	1.9321	2.68562	1.17898	3.72827	1.11602	2.40439	5.18010	.719425
1.40	1.9600	2.74400	1.18322	3.74166	1.11869	2.41014	5.19249	.714286
1.41	1.9881	2.80322	1.18743	3.75500	1.12135	2.41587	5.20483	.709220
1.42	2.0164	2.86329	1.19164	3.76829	1.12399	2.42156	5.21710	.704225
1.43	2.0449	2.92421	1.19583	3.78153	1.12662	2.42724	5.22932	.699301
1.44	2.0736	2.98598	1.20000	3.79473	1.12924	2.43288	5.24148	.694444
1.45	2.1025	3.04863	1.20416	3.80789	1.13185	2.43850	5.25359	.689655
1.46	2.1316	3.11214	1.20830	3.82099	1.13445	2.44409	5.26564	.684932
1.47	2.1609	3.17652	1.21244	3.83406	1.13703	2.44966	5.27763	.680272
1.48	2.1904	3.24179	1.21655	3.84708	1.13960	2.45520	5.28957	.675676
1.49	2.2201	3.30795	1.22066	3.86005	1.14216	2.46072	5.30146	.671141
1.50	2.2500	3.37500	1.22474	3.87298	1.14471	2.46621	5.31329	.666667

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
1.51	2.2801	3.44295	1.22882	3.88587	1.14725	2.47168	5.32507	.662252
1.52	2.3104	3.51181	1.23288	3.89872	1.14978	2.47713	5.33680	.657895
1.53	2.3409	3.58158	1.23693	3.91152	1.15230	2.48255	5.34848	.653595
1.54	2.3716	3.65226	1.24097	3.92428	1.15480	2.48794	5.36011	.649351
1.55	2.4025	3.72388	1.24499	3.93700	1.15729	2.49332	5.37169	.645161
1.56	2.4336	3.79642	1.24900	3.94968	1.15978	2.49866	5.38321	.641026
1.57	2.4649	3.86989	1.25300	3.96232	1.16225	2.50399	5.39469	.636943
1.58	2.4964	3.94431	1.25698	3.97492	1.16471	2.50930	5.40612	.632911
1.59	2.5281	4.01968	1.26095	3.98748	1.16717	2.51458	5.41750	.628931
1.60	2.5600	4.09600	1.26491	4.00000	1.16961	2.51984	5.42884	.625000
1.61	2.5921	4.17328	1.26886	4.01248	1.17204	2.52508	5.44012	.621118
1.62	2.6244	4.25153	1.27279	4.02492	1.17446	2.53030	5.45136	.617284
1.63	2.6569	4.33075	1.27671	4.03733	1.17687	2.53549	5.46256	.613497
1.64	2.6896	4.41094	1.28062	4.04969	1.17927	2.54067	5.47370	.609756
1.65	2.7225	4.49213	1.28452	4.06202	1.18167	2.54582	5.48481	.606061
1.66	2.7556	4.57430	1.28841	4.07431	1.18405	2.55095	5.49586	.602410
1.67	2.7889	4.65746	1.29228	4.08656	1.18642	2.55607	5.50688	.598802
1.68	2.8224	4.74163	1.29615	4.09878	1.18878	2.56116	5.51785	.595238
1.69	2.8561	4.82681	1.30000	4.11096	1.19114	2.56623	5.52877	.591716
1.70	2.8900	4.91300	1.30384	4.12311	1.19348	2.57128	5.53966	.588235
1.71	2.9241	5.00021	1.30767	4.13521	1.19582	2.57631	5.55050	.584795
1.72	2.9584	5.08845	1.31149	4.14729	1.19815	2.58133	5.56130	.581395
1.73	2.9929	5.17772	1.31529	4.15933	1.20046	2.58632	5.57205	.578035
1.74	3.0276	5.26802	1.31909	4.17133	1.20277	2.59129	5.58277	.574713
1.75	3.0625	5.35938	1.32288	4.18330	1.20507	2.59625	5.59344	.571429
1.76	3.0976	5.45178	1.32665	4.19524	1.20736	2.60118	5.60408	.568182
1.77	3.1329	5.54523	1.33041	4.20714	1.20964	2.60610	5.61467	.564972
1.78	3.1684	5.63975	1.33417	4.21900	1.21192	2.61100	5.62523	.561798
1.79	3.2041	5.73534	1.33791	4.23084	1.21418	2.61588	5.63574	.558659
1.80	3.2400	5.83200	1.34164	4.24264	1.21644	2.62074	5.64622	.555556
1.81	3.2761	5.92974	1.34536	4.25441	1.21869	2.62558	5.65665	.552486
1.82	3.3124	6.02857	1.34907	4.26615	1.22093	2.63041	5.66705	.549451
1.83	3.3489	6.12849	1.35277	4.27785	1.22316	2.63522	5.67741	.546448
1.84	3.3856	6.22950	1.35647	4.28952	1.22539	2.64001	5.68773	.543478
1.85	3.4225	6.33163	1.36015	4.30116	1.22760	2.64479	5.69802	.540541
1.86	3.4596	6.43486	1.36382	4.31277	1.22981	2.64954	5.70827	.537634
1.87	3.4969	6.53920	1.36748	4.32435	1.23201	2.65428	5.71848	.534759
1.88	3.5344	6.64467	1.37113	4.33590	1.23420	2.65900	5.72865	.531915
1.89	3.5721	6.75127	1.37477	4.34741	1.23639	2.66371	5.73879	.529101
1.90	3.6100	6.85900	1.37840	4.35890	1.23856	2.66840	5.74890	.526316
1.91	3.6481	6.96787	1.38203	4.37035	1.24073	2.67307	5.75897	.523560
1.92	3.6864	7.07789	1.38564	4.38178	1.24289	2.67773	5.76900	.520833
1.93	3.7249	7.18906	1.38924	4.39318	1.24505	2.68237	5.77900	.518135
1.94	3.7636	7.30138	1.39284	4.40454	1.24719	2.68700	5.78896	.515464
1.95	3.8025	7.41488	1.39642	4.41588	1.24933	2.69161	5.79889	.512821
1.96	3.8416	7.52954	1.40000	4.42719	1.25146	2.69620	5.80879	.510204
1.97	3.8809	7.64537	1.40357	4.43847	1.25359	2.70078	5.81865	.507614
1.98	3.9204	7.76239	1.40712	4.44972	1.25571	2.70534	5.82848	.505051
1.99	3.9601	7.88060	1.41067	4.46094	1.25782	2.70989	5.83827	.502513
2.00	4.0000	8.00000	1.41421	4.47214	1.25992	2.71442	5.84804	.500000

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
2.01	4.0401	8.12060	1.41774	4.48330	1.26202	2.71893	5.85777	.497512
2.02	4.0804	8.24241	1.42127	4.49444	1.26411	2.72343	5.86746	.495050
2.03	4.1209	8.36543	1.42478	4.50555	1.26619	2.72792	5.87713	.492611
2.04	4.1616	8.48966	1.42829	4.51664	1.26827	2.73239	5.88677	.490196
2.05	4.2025	8.61513	1.43178	4.52769	1.27033	2.73685	5.89637	.487805
2.06	4.2436	8.74182	1.43527	4.53872	1.27240	2.74129	5.90594	.485437
2.07	4.2849	8.86974	1.43875	4.54973	1.27445	2.74572	5.91548	.483092
2.08	4.3264	8.99891	1.44222	4.56070	1.27650	2.75014	5.92499	.480769
2.09	4.3681	9.12933	1.44568	4.57165	1.27854	2.75454	5.93447	.478469
2.10	4.4100	9.26100	1.44914	4.58258	1.28058	2.75893	5.94392	.476191
2.11	4.4521	9.39393	1.45258	4.59347	1.28261	2.76330	5.95334	.473934
2.12	4.4944	9.52813	1.45602	4.60435	1.28463	2.76766	5.96273	.471698
2.13	4.5369	9.66360	1.45945	4.61519	1.28665	2.77200	5.97209	.469484
2.14	4.5796	9.80034	1.46287	4.62601	1.28866	2.77633	5.98142	.467290
2.15	4.6225	9.93838	1.46629	4.63681	1.29066	2.78065	5.99073	.465116
2.16	4.6656	10.0777	1.46969	4.64758	1.29266	2.78495	6.00000	.462963
2.17	4.7089	10.2183	1.47309	4.65833	1.29465	2.78924	6.00925	.460830
2.18	4.7524	10.3602	1.47648	4.66905	1.29664	2.79352	6.01846	.458716
2.19	4.7961	10.5035	1.47986	4.67974	1.29862	2.79779	6.02765	.456621
2.20	4.8400	10.6480	1.48324	4.69042	1.30059	2.80204	6.03681	.454546
2.21	4.8841	10.7939	1.48661	4.70106	1.30256	2.80628	6.04594	.452489
2.22	4.9284	10.9410	1.48997	4.71169	1.30452	2.81051	6.05505	.450451
2.23	4.9729	11.0896	1.49332	4.72229	1.30648	2.81472	6.06413	.448431
2.24	5.0176	11.2394	1.49666	4.73286	1.30843	2.81892	6.07318	.446429
2.25	5.0625	11.3906	1.50000	4.74342	1.31037	2.82311	6.08220	.444444
2.26	5.1076	11.5432	1.50333	4.75395	1.31231	2.82728	6.09120	.442478
2.27	5.1529	11.6971	1.50665	4.76445	1.31424	2.83145	6.10017	.440529
2.28	5.1984	11.8524	1.50997	4.77493	1.31617	2.83560	6.10911	.438597
2.29	5.2441	12.0090	1.51327	4.78539	1.31809	2.83974	6.11803	.436681
2.30	5.2900	12.1670	1.51658	4.79583	1.32001	2.84387	6.12693	.434783
2.31	5.3361	12.3264	1.51987	4.80625	1.32192	2.84798	6.13579	.432900
2.32	5.3824	12.4872	1.52315	4.81664	1.32382	2.85209	6.14463	.431035
2.33	5.4289	12.6493	1.52643	4.82701	1.32572	2.85618	6.15345	.429185
2.34	5.4756	12.8129	1.52971	4.83735	1.32761	2.86026	6.16224	.427350
2.35	5.5225	12.9779	1.53297	4.84768	1.32950	2.86433	6.17101	.425532
2.36	5.5696	13.1443	1.53623	4.85798	1.33139	2.86838	6.17975	.423729
2.37	5.6169	13.3121	1.53948	4.86826	1.33326	2.87243	6.18846	.421941
2.38	5.6644	13.4813	1.54272	4.87852	1.33514	2.87646	6.19715	.420168
2.39	5.7121	13.6519	1.54596	4.88876	1.33700	2.88049	6.20582	.418410
2.40	5.7600	13.8240	1.54919	4.89898	1.33887	2.88450	6.21447	.416667
2.41	5.8081	13.9975	1.55242	4.90918	1.34072	2.88850	6.22308	.414938
2.42	5.8564	14.1725	1.55563	4.91935	1.34257	2.89249	6.23168	.413223
2.43	5.9049	14.3489	1.55885	4.92950	1.34442	2.89647	6.24025	.411523
2.44	5.9536	14.5268	1.56205	4.93964	1.34626	2.90044	6.24880	.409836
2.45	6.0025	14.7061	1.56525	4.94975	1.34810	2.90439	6.25732	.408163
2.46	6.0516	14.8869	1.56844	4.95984	1.34993	2.90834	6.26583	.406504
2.47	6.1009	15.0692	1.57162	4.96991	1.35176	2.91227	6.27431	.404858
2.48	6.1504	15.2530	1.57480	4.97996	1.35358	2.91620	6.28276	.403226
2.49	6.2001	15.4382	1.57797	4.98999	1.35540	2.92011	6.29119	.401606
2.50	6.2500	15.6250	1.58114	5.00000	1.35721	2.92402	6.29961	.400000

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
2.51	6.3001	15.8133	1.58430	5.00999	1.35902	2.92791	6.30799	.398406
2.52	6.3504	16.0030	1.58745	5.01996	1.36082	2.93179	6.31636	.396825
2.53	6.4009	16.1943	1.59060	5.02991	1.36262	2.93567	6.32470	.395257
2.54	6.4516	16.3871	1.59374	5.03984	1.36441	2.93953	6.33303	.393701
2.55	6.5025	16.5814	1.59687	5.04975	1.36620	2.94338	6.34133	.392157
2.56	6.5536	16.7772	1.60000	5.05964	1.36798	2.94723	6.34960	.390625
2.57	6.6049	16.9746	1.60312	5.06952	1.36976	2.95106	6.35786	.389105
2.58	6.6564	17.1735	1.60624	5.07937	1.37153	2.95488	6.36610	.387597
2.59	6.7081	17.3740	1.60935	5.08920	1.37330	2.95869	6.37431	.386100
2.60	6.7600	17.5760	1.61245	5.09902	1.37507	2.96250	6.38250	.384615
2.61	6.8121	17.7796	1.61555	5.10882	1.37683	2.96629	6.39068	.383142
2.62	6.8644	17.9847	1.61864	5.11859	1.37859	2.97007	6.39883	.381679
2.63	6.9169	18.1914	1.62173	5.12835	1.38034	2.97385	6.40696	.380228
2.64	6.9696	18.3997	1.62481	5.13809	1.38208	2.97761	6.41507	.378788
2.65	7.0225	18.6096	1.62788	5.14782	1.38383	2.98137	6.42316	.377359
2.66	7.0756	18.8211	1.63095	5.15752	1.38557	2.98511	6.43123	.375940
2.67	7.1289	19.0342	1.63401	5.16720	1.38730	2.98885	6.43928	.374532
2.68	7.1824	19.2488	1.63707	5.17687	1.38903	2.99257	6.44731	.373134
2.69	7.2361	19.4651	1.64012	5.18652	1.39076	2.99629	6.45531	.371747
2.70	7.2900	19.6830	1.64317	5.19615	1.39248	3.00000	6.46330	.370370
2.71	7.3441	19.9025	1.64621	5.20577	1.39419	3.00370	6.47127	.369004
2.72	7.3984	20.1236	1.64924	5.21536	1.39591	3.00739	6.47922	.367647
2.73	7.4529	20.3464	1.65227	5.22494	1.39761	3.01107	6.48715	.366300
2.74	7.5076	20.5708	1.65529	5.23450	1.39932	3.01474	6.49507	.364964
2.75	7.5625	20.7969	1.65831	5.24404	1.40102	3.01841	6.50296	.363636
2.76	7.6176	21.0246	1.66132	5.25357	1.40272	3.02206	6.51083	.362319
2.77	7.6729	21.2539	1.66433	5.26308	1.40441	3.02571	6.51868	.361011
2.78	7.7284	21.4850	1.66733	5.27257	1.40610	3.02934	6.52652	.359712
2.79	7.7841	21.7176	1.67033	5.28205	1.40778	3.03297	6.53434	.358423
2.80	7.8400	21.9520	1.67332	5.29150	1.40946	3.03659	6.54213	.357142
2.81	7.8961	22.1880	1.67631	5.30094	1.41114	3.04020	6.54991	.355872
2.82	7.9524	22.4258	1.67929	5.31037	1.41281	3.04380	6.55767	.354610
2.83	8.0089	22.6652	1.68226	5.31977	1.41448	3.04740	6.56541	.353357
2.84	8.0656	22.9063	1.68523	5.32917	1.41614	3.05098	6.57314	.352113
2.85	8.1225	23.1491	1.68819	5.33854	1.41780	3.05456	6.58084	.350877
2.86	8.1796	23.3937	1.69115	5.34790	1.41946	3.05813	6.58853	.349650
2.87	8.2369	23.6399	1.69411	5.35724	1.42111	3.06169	6.59620	.348432
2.88	8.2944	23.8879	1.69706	5.36656	1.42276	3.06524	6.60385	.347222
2.89	8.3521	24.1376	1.70000	5.37587	1.42440	3.06878	6.61149	.346021
2.90	8.4100	24.3890	1.70294	5.38516	1.42604	3.07232	6.61911	.344828
2.91	8.4681	24.6422	1.70587	5.39444	1.42768	3.07585	6.62671	.343643
2.92	8.5264	24.8971	1.70880	5.40370	1.42931	3.07936	6.63429	.342466
2.93	8.5849	25.1538	1.71172	5.41295	1.43094	3.08287	6.64185	.341297
2.94	8.6436	25.4122	1.71464	5.42218	1.43257	3.08638	6.64940	.340136
2.95	8.7025	25.6724	1.71756	5.43139	1.43419	3.08987	6.65693	.338983
2.96	8.7616	25.9343	1.72047	5.44059	1.43581	3.09336	6.66444	.337838
2.97	8.8209	26.1981	1.72337	5.44977	1.43743	3.09684	6.67194	.336700
2.98	8.8804	26.4636	1.72627	5.45894	1.43904	3.10031	6.67942	.335571
2.99	8.9401	26.7309	1.72916	5.46809	1.44065	3.10378	6.68688	.334448
3.00	9.0000	27.0000	1.73205	5.47723	1.44225	3.10723	6.69433	.333333

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
3.01	9.0601	27.2709	1.73494	5.48635	1.44385	3.11068	6.70176	.332226
3.02	9.1204	27.5436	1.73781	5.49545	1.44545	3.11412	6.70917	.331126
3.03	9.1809	27.8181	1.74069	5.50454	1.44704	3.11755	6.71657	.330033
3.04	9.2416	28.0945	1.74356	5.51362	1.44863	3.12098	6.72395	.328947
3.05	9.3025	28.3726	1.74642	5.52268	1 45022	3.12440	6.73132	.327869
3.06	9.3636	28.6526	1.74929	5.53173	1.45180	3.12781	6.73866	.326797
3.07	9.4249	28.9344	1.75214	5.54076	1.45338	3.13121	6.74600	.325733
3.08	9.4864	29.2181	1.75499	5.54977	1.45496	3.13461	6.75331	.324675
3.09	9.5481	29.5036	1.75784	5.55878	1.45653	3.13800	6.76061	.323625
3.10	9.6100	29.7910	1.76068	5.56776	1.45810	3.14138	6.76790	322581
3.11	9.6721	30.0802	1.76352	5.57674	1.45967	3.14475	6.77517	.321543
3.12	9.7344	30.3713	1.76635	5.58570	1.46123	3.14812	6.78242	.320513
3.13	9.7969	30.6643	1.76918	5.59464	1.46279	3.15148	6.78966	.319489
3.14	9.8596	30.9591	1.77200	5.60357	1.46434	3.15484	6.79688	.318471
3.15	9.9225	31.2559	1.77482	5.61249	1.46590	3.15818	6.80409	.317460
3.16	9.9856	31.5545	1.77764	5.62139	1.46745	3.16152	6.81128	.316456
3.17	10.0489	31.8550	1.78045	5.63028	1.46899	3.16485	6.81846	.315457
3.18	10.1124	32.1574	1.78326	5.63915	1.47054	3.16817	6.82562	.314465
3.19	10.1761	32.4618	1.78606	5.64801	1.47208	3.17149	6.83277	.313480
3.20	10.2400	32.7680	1.78885	5.65685	1.47361	3.17480	6.83990	.312500
3.21	10.3041	33.0762	1.79165	5.66569	1.47515	3.17811	6.84702	.311527
3.22	10.3684	33.3862	1.79444	5.67450	1.47668	3.18140	6.85412	.310559
3.23	10.4329	33.6983	1.79722	5.68331	1.47820	3.18469	6.86121	.309598
3.24	10.4976	34.0122	1.80000	5.69210	1.47973	3.18798	6.86829	.308642
3.25	10.5625	34.3281	1.80278	5.70088	1.48125	3.19125	6.87534	.307692
3.26	10.6276	34.6460	1.80555	5.70964	1.48277	3.19452	6.88239	.306749
3.27	10.6929	34.9658	1.80831	5.71839	1.48428	3.19779	6.88942	.305810
3.28	10.7584	35.2876	1.81108	5.72713	1.48579	3.20104	6.89643	.304878
3.29	10.8241	35.6129	1.81384	5.73585	1.48730	3.20429	6.90344	.303951
3.30	10.8900	35.9370	1.81659	5.74456	1.48881	3.20753	6.91042	.303030
3.31	10.9561	36.2647	1.81934	5.75326	1.49031	3.21077	6.91740	.302115
3.32	11.0224	36.5944	1.82209	5.76194	1.49181	3.21400	6.92436	.301205
3.33	11.0889	36.9260	1.82483	5.77062	1.49330	3.21723	6.93130	.300300
3.34	11.1556	37.2597	1.82757	5.77927	1.49480	3.22044	6.93823	.299401
3.35	11.2225	37.5954	1.83030	5.78792	1.49629	3.22365	6.94515	.298508
3.36	11.2896	37.9331	1.83303	5.79655	1.49777	3.22686	6.95205	.297619
3.37	11.3569	38.2728	1.83576	5.80517	1.49926	3.23005	6.95894	.296736
3.38	11.4244	38.6145	1.83848	5.81378	1.50074	3.23325	6.96582	.295858
3.39	11.4921	38.9582	1.84120	5.82237	1.50222	3.23643	6.97268	.294985
3.40	11.5600	39.3040	1.84391	5.83095	1.50369	3.23961	6.97953	.294118
3.41	11.6281	39.6518	1.84662	5.83952	1.50517	3.24278	6.98637	.293255
3.42	11.6964	40.0017	1.84932	5.84808	1.50664	3.24595	6.99319	.292398
3.43	11.7649	40.3536	1.85203	5.85662	1.50810	3.24911	7.00000	.291545
3.44	11.8336	40.7076	1.85472	5.86515	1.50957	3.25227	7.00680	.290698
3.45	11.9025	41.0636	1.85742	5.87367	1.51103	3.25542	7.01358	.289855
3.46	11.9716	41.4217	1.86011	5.88218	1.51249	3.25856	7.02035	.289017
3.47	12.0409	41.7819	1.86279	5.89067	1.51394	3.26169	7.02711	.288184
3.48	12.1104	42 1442	1.86548	5.89915	1.51540	3.26482	7.03385	.287356
3.49	12.1801	42.5085	1.86815	5.90762	1.51685	3.26795	7.04058	.286533
3.50	12.2500	42.8750	1.87083	5.91608	1.51829	3.27107	7.04730	.285714

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
3.51	12.3201	43.2436	1.87350	5.92453	1.51974	3.27418	7.05400	.284900
3.52	12.3904	43.6142	1.87617	5.93296	1.52118	3.27729	7.06070	.284091
3.53	12.4609	43.9870	1.87883	5.94138	1.52262	3.28039	7.06738	.283286
3.54	12.5316	44.3619	1.88149	5.94979	1.52406	3.28348	7.07404	.282486
3.55	12.6025	44.7389	1.88414	5.95819	1.52549	3.28657	7.08070	.281690
3.56	12.6736	45.1180	1.88680	5.96657	1.52692	3.28965	7.08734	.280899
3.57	12.7449	45.4993	1.88944	5.97495	1.52835	3.29273	7.09397	.280112
3.58	12.8164	45.8827	1.89209	5.98331	1.52978	3.29580	7.10059	.279330
3.59	12.8881	46.2683	1.89473	5.99166	1.53120	3.29887	7.10719	.278552
3.60	12.9600	46.6560	1.89737	6.00000	1.53262	3.30193	7.11379	.277778
3.61	13.0321	47.0459	1.90000	6.00833	1.53404	3.30498	7.12037	.277008
3.62	13.1044	47.4379	1.90263	6.01664	1.53545	3.30803	7.12694	.276243
3.63	13.1769	47.8321	1.90526	6.02495	1.53686	3.31107	7.13349	.275482
3.64	13.2496	48.2285	1.90788	6.03324	1.53827	3.31411	7.14004	.274725
3.65	13.3225	48.6271	1.91050	6.04152	1.53968	3.31714	7.14657	.273973
3.66	13.3956	49.0279	1.91311	6.04979	1.54109	3.32017	7.15309	.273224
3.67	13.4689	49.4309	1.91572	6.05805	1.54249	3.32319	7.15960	.272480
3.68	13.5424	49.8360	1.91833	6.06630	1.54389	3.32621	7.16610	.271739
3.69	13.6161	50.2434	1.92094	6.07454	1.54529	3.32922	7.17258	.271003
3.70	13.6900	50.6530	1.92354	6.08276	1.54668	3.33222	7.17905	.270270
3.71	13.7641	51.0648	1.92614	6.09098	1.54807	3.33522	7.18552	.269542
3.72	13.8384	51.4788	1.92873	6.09918	1.54946	3.33822	7.19197	.268817
3.73	13.9129	51.8951	1.93132	6.10737	1.55085	3.34120	7.19841	.268097
3.74	13.9876	52.3136	1.93391	6.11555	1.55223	3.34419	7.20483	.267380
3.75	14.0625	52.7344	1.93649	6.12372	1.55362	3.34716	7.21125	.266667
3.76	14.1376	53.1574	1.93907	6.13188	1.55500	3.35014	7.21765	.265957
3.77	14.2129	53.5826	1.94165	6.14003	1.55637	3.35310	7.22405	.265252
3.78	14.2884	54.0102	1.94422	6.14817	1.55775	3.35607	7.23043	.264550
3.79	14.3641	54.4399	1.94679	6.15630	1.55912	3.35902	7.23680	.263852
3.80	14.4400	54.8720	1.94936	6.16441	1.56049	3.36198	7.24316	.263158
3.81	14.5161	55.3063	1.95192	6.17252	1.56186	3.36492	7.24950	.262467
3.82	14.5924	55.7430	1.95448	6.18061	1.56322	3.36786	7.25584	.261780
3.83	14.6689	56.1819	1.95704	6.18870	1.56459	3.37080	7.26217	.261097
3.84	14.7456	56.6231	1.95959	6.19677	1.56595	3.37373	7.26848	.260417
3.85	14.8225	57.0666	1.96214	6.20484	1.56731	3.37666	7.27479	.259740
3.86	14.8996	57.5125	1.96469	6.21289	1.56866	3.37958	7.28108	.259067
3.87	14.9769	57.9606	1.96723	6.22093	1.57001	3.38249	7.28736	.258398
3.88	15.0544	58.4111	1.96977	6.22896	1.57137	3.38540	7.29363	.257732
3.89	15.1321	58.8639	1.97231	6.23699	1.57271	3.38831	7.29989	.257069
3.90	15.2100	59.3190	1.97484	6.24500	1.57406	3.39121	7.30614	.256410
3.91	15.2881	59.7765	1.97737	6.25300	1.57541	3.39411	7.31238	.255755
3.92	15.3664	60.2363	1.97990	6.26099	1.57675	3.39700	7.31861	.255102
3.93	15.4449	60.6985	1.98242	6.26897	1.57809	3.39988	7.32483	.254453
3.94	15.5236	61.1630	1.98494	6.27694	1.57942	3.40277	7.33104	.253807
3.95	15.6025	61.6299	1.98746	6.28490	1.58076	3.40564	7.33723	.253165
3.96	15.6816	62.0991	1.98997	6.29285	1.58209	3.40851	7.34342	.252525
3.97	15.7609	62.5708	1.99249	6.30079	1.58342	3.41138	7.34960	.251889
3.98	15.8404	63.0448	1.99499	6.30872	1.58475	3.41424	7.35576	.251256
3.99	15.9201	63.5212	1.99750	6.31664	1.58608	3.41710	7.36192	.250627
4.00	16.0000	64.0000	2.00000	6.32456	1.58740	3.41995	7.36806	.250000

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
4.01	16.0801	64.4812	2.00250	6.33246	1.58872	3.42280	7.37420	.249377
4.02	16.1604	64.9648	2.00499	6.34035	1.59004	3.42564	7.38032	.248756
4.03	16.2409	65.4506	2.00749	6.34823	1.59136	3.42848	7.38644	.248139
4.04	16.3216	65.9393	2.00998	6.35610	1.59267	3.43131	7.39254	.247525
4.05	16.4025	66.4301	2.01246	6.36396	1.59399	3.43414	7.39864	.246914
4.06	16.4836	66.9234	2.01494	6.37181	1.59530	3.43697	7.40472	.246305
4.07	16.5649	67.4191	2.01742	6.37966	1.59661	3.43979	7.41080	.245700
4.08	16.6464	67.9173	2.01990	6.38749	1.59791	3.44260	7.41686	.245098
4.09	16.7281	68.4179	2.02237	6.39531	1.59922	3.44541	7.42291	.244499
4.10	16.8100	68.9210	2.02485	6.40312	1.60052	3.44822	7.42896	.243902
4.11	16.8921	69.4265	2.02731	6.41093	1.60182	3.45102	7.43499	.243309
4.12	16.9744	69.9345	2.02978	6.41872	1.60312	3.45382	7.44102	.242718
4.13	17.0569	70.4450	2.03224	6.42651	1.60441	3.45661	7.44703	.242131
4.14	17.1396	70.9579	2.03470	6.43428	1.60571	3.45939	7.45304	.241546
4.15	17.2225	71.4734	2.03715	6.44205	1.60700	3.46218	7.45904	.240964
4.16	17.3056	71.9913	2.03961	6.44981	1.60829	3.46496	7.46502	.240385
4.17	17.3889	72.5117	2.04206	6.45755	1.60958	3.46773	7.47100	.239808
4.18	17.4724	73.0346	2.04450	6.46529	1.61086	3.47050	7.47697	.239234
4.19	17.5561	73.5601	2.04695	6.47302	1.61215	3.47327	7.48292	.238664
4.20	17.6400	74.0880	2.04939	6.48074	1.61343	3.47603	7.48887	.238095
4.21	17.7241	74.6185	2.05183	6.48845	1.61471	3.47878	7.49481	.237530
4.22	17.8084	75.1514	2.05426	6.49615	1.61599	3.48154	7.50074	.236967
4.23	17.8929	75.6870	2.05670	6.50385	1.61726	3.48428	7.50666	.236407
4.24	17.9776	76.2250	2.05913	6.51153	1.61853	3.48703	7.51257	.235849
4.25	18.0625	76.7656	2.06155	6.51920	1.61981	3.48977	7.51847	.235294
4.26	18.1476	77.3088	2.06398	6.52687	1.62108	3.49250	7.52437	.234742
4.27	18.2329	77.8545	2.06640	6.53452	1.62234	3.49523	7.53025	.234192
4.28	18.3184	78.4028	2.06882	6.54217	1.62361	3.49796	7.53612	.233645
4.29	18.4041	78.9536	2.07123	6.54981	1.62487	3.50068	7.54199	.233100
4.30	18.4900	79.5070	2.07364	6.55744	1.62613	3.50340	7.54784	.232558
4.31	18.5761	80.0630	2.07605	6.56506	1.62739	3.50611	7.55369	.232019
4.32	18.6624	80.6216	2.07846	6.57267	1.62865	3.50882	7.55953	.231482
4.33	18.7489	81.1827	2.08087	6.58027	1.62991	3.51153	7.56535	.230947
4.34	18.8356	81.7465	2.08327	6.58787	1.63116	3.51423	7.57117	.230415
4.35	18.9225	82.3129	2.08567	6.59545	1.63241	3.51692	7.57698	.229885
4.36	19.0096	82.8819	2.08806	6.60303	1.63366	3.51962	7.58279	.229358
4.37	19.0969	83.4535	2.09045	6.61060	1.63491	3.52231	7.58858	.228833
4.38	19.1844	84.0277	2.09284	6.61816	1.63616	3.52499	7.59436	.228311
4.39	19.2721	84.6045	2.09523	6.62571	1.63740	3.52767	7.60014	.227790
4.40	19.3600	85.1840	2.09762	6.63325	1.63864	3.53035	7.60590	.227273
4.41	19.4481	85.7661	2.10000	6.64078	1.63988	3.53302	7.61166	.226757
4.42	19.5364	86.3509	2.10238	6.64831	1.64112	3.53569	7.61741	.226244
4.43	19.6249	86.9383	2.10476	6.65582	1.64236	3.53835	7.62315	.225734
4.44	19.7136	87.5284	2.10713	6.66333	1.64359	3.54101	7.62888	.225225
4.45	19.8025	88.1211	2.10950	6.67083	1.64483	3.54367	7.63461	.224719
4.46	19.8916	88.7165	2.11187	6.67832	1.64606	3.54632	7.64032	.224215
4.47	19.9809	89.3146	2.11424	6.68581	1.64729	3.54897	7.64603	.223714
4.48	20.0704	89.9154	2.11660	6.69328	1.64851	3.55162	7.65172	.223214
4.49	20.1601	90.5188	2.11896	6.70075	1.64974	3.55426	7.65741	.222717
4.50	20.2500	91.1250	2.12132	6.70820	1.65096	3.55689	7.66309	.222222

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
4.51	20.3401	91.7339	2.12368	6.71565	1.65219	3.55953	7.66877	.221730
4.52	20.4304	92.3454	2.12603	6.72309	1.65341	3.56215	7.67443	.221239
4.53	20.5209	92.9597	2.12838	6.73053	1.65462	3.56478	7.68009	.220751
4.54	20.6116	93.5767	2.13073	6.73795	1.65584	3.56740	7.68573	.220264
4.55	20.7025	94.1964	2.13307	6.74537	1.65706	3.57002	7.69137	.219780
4.56	20.7936	94.8188	2.13542	6.75278	1.65827	3.57263	7.69700	.219298
4.57	20.8849	95.4440	2.13776	6.76018	1.65948	3.57524	7.70262	.218818
4.58	20.9764	96.0719	2.14009	6.76757	1.66069	3.57785	7.70824	.218341
4.59	21.0681	96.7026	2.14243	6.77495	1.66190	3.58045	7.71384	.217865
4.60	21.1600	97.3360	2.14476	6.78233	1.66310	3.58305	7.71944	.217391
4.61	21.2521	97.9722	2.14709	6.78970	1.66431	3.58564	7.72503	.216920
4.62	21.3444	98.6111	2.14942	6.79706	1.66551	3.58823	7.73061	.216450
4.63	21.4369	99.2528	2.15174	6.80441	1.66671	3.59082	7.73619	.215983
4.64	21.5296	99.8973	2.15407	6.81175	1.66791	3.59340	7.74175	.215517
4.65	21.6225	100.545	2.15639	6.81909	1.66911	3.59598	7.74731	.215054
4.66	21.7156	101.195	2.15870	6.82642	1.67030	3.59856	7.75286	.214592
4.67	21.8089	101.848	2.16102	6.83374	1.67150	3.60113	7.75840	.214133
4.68	21.9024	102.503	2.16333	6.84105	1.67269	3.60370	7.76394	.213675
4.69	21.9961	103.162	2.16564	6.84836	1.67388	3.60626	7.76946	.213220
4.70	22.0900	103.823	2.16795	6.85565	1.67507	3.60883	7.77498	.212766
4.71	22.1841	104.487	2.17025	6.86294	1.67626	3.61138	7.78049	.212314
4.72	22.2784	105.154	2.17256	6.87023	1.67744	3.61394	7.78599	.211864
4.73	22.3729	105.824	2.17486	6.87750	1.67863	3.61649	7.79149	.211417
4.74	22.4676	106.496	2.17715	6.88477	1.67981	3.61904	7.79697	.210971
4.75	22.5625	107.172	2.17945	6.89202	1.68099	3.62158	7.80245	.210526
4.76	22.6576	107.850	2.18174	6.89928	1.68217	3.62412	7.80793	.210084
4.77	22.7529	108.531	2.18403	6.90652	1.68334	3.62665	7.81339	.209644
4.78	22.8484	109.215	2.18632	6.91375	1.68452	3.62919	7.81885	.209205
4.79	22.9441	109.902	2.18861	6.92098	1.68569	3.63171	7.82429	.208768
4.80	23.0400	110.592	2.19089	6.92820	1.68687	3.63424	7.82974	.208333
4.81	23.1361	111.285	2.19317	6.93542	1.68804	3.63676	7.83517	.207900
4.82	23.2324	111.980	2.19545	6.94262	1.68920	3.63928	7.84059	.207469
4.83	23.3289	112.679	2.19773	6.94982	1.69037	3.64180	7.84601	.207039
4.84	23.4256	113.380	2.20000	6.95701	1.69154	3.64431	7.85142	.206612
4.85	23.5225	114.084	2.20227	6.96419	1.69270	3.64682	7.85683	.206186
4.86	23.6196	114.791	2.20454	6.97137	1.69386	3.64932	7.86222	.205761
4.87	23.7169	115.501	2.20681	6.97854	1.69503	3.65182	7.86761	.205339
4.88	23.8144	116.214	2.20907	6.98570	1.69619	3.65432	7.87299	.204918
4.89	23.9121	116.930	2.21133	6.99285	1.69734	3.65682	7.87837	.204499
4.90	24.0100	117.649	2.21359	7.00000	1.69850	3.65931	7.88374	.204082
4.91	24.1081	118.371	2.21585	7.00714	1.69965	3.66179	7.88909	.203666
4.92	24.2064	119.095	2.21811	7.01427	1.70081	3.66428	7.89445	.203252
4.93	24.3049	119.823	2.22036	7.02140	1.70196	3.66676	7.89979	.202840
4.94	24.4036	120.554	2.22261	7.02851	1.70311	3.66924	7.90513	.202429
4.95	24.5025	121.287	2.22486	7.03562	1.70426	3.67171	7.91046	.202020
4.96	24.6016	122.024	2.22711	7.04273	1.70540	3.67418	7.91578	.201613
4.97	24.7009	122.763	2.22935	7.04982	1.70655	3.67665	7.92110	.201207
4.98	24.8004	123.506	2.23159	7.05691	1.70769	3.67911	7.92641	.200803
4.99	24.9001	124.251	2.23383	7.06399	1.70884	3.68157	7.93171	.200401
5.00	25.0000	125.000	2.23607	7.07107	1.70998	3.68403	7.93701	.200000

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
5.01	25.1001	125.752	2.23830	7.07814	1.71112	3.68649	7.94229	.199601
5.02	25.2004	126.506	2.24054	7.08520	1.71225	3.68894	7.94757	.199203
5.03	25.3009	127.264	2.24277	7.09225	1.71339	3.69138	7.95285	.198807
5.04	25.4016	128.024	2.24499	7.09930	1.71452	3.69383	7.95811	.198413
5.05	25.5025	128.788	2.24722	7.10634	1.71566	3.69627	7.96337	.198020
5.06	25.6036	129.554	2.24944	7.11337	1.71679	3.69871	7.96863	.197629
5.07	25.7049	130.324	2.25167	7.12039	1.71792	3.70114	7.97387	.197239
5.08	25.8064	131.097	2.25389	7.12741	1.71905	3.70358	7.97913	.196850
5.09	25.9081	131.872	2.25610	7.13442	1.72017	3.70600	7.98434	.196464
5.10	26.0100	132.651	2.25832	7.14143	1.72130	3.70843	7.98957	.196078
5.11	26.1121	133.433	2.26053	7.14843	1.72242	3.71085	7.99479	.195695
5.12	26.2144	134.218	2.26274	7.15542	1.72355	3.71327	8.00000	.195313
5.13	26.3169	135.006	2.26495	7.16240	1.72467	3.71566	8.00520	.194932
5.14	26.4196	135.797	2.26716	7.16938	1.72579	3.71810	8.01040	.194553
5.15	26.5225	136.591	2.26936	7.17635	1.72691	3.72051	8.01559	.194175
5.16	26.6256	137.388	2.27156	7.18331	1.72802	3.72292	8.02078	.193798
5.17	26.7289	138.188	2.27376	7.19027	1.72914	3.72532	8.02596	.193424
5.18	26.8324	138.992	2.27596	7.19722	1.73025	3.72772	8.03113	.193050
5.19	26.9361	139.798	2.27816	7.20417	1.73137	3.73012	8.03629	.192678
5.20	27.0400	140.608	2.28035	7.21110	1.73248	3.73251	8.04145	.192308
5.21	27.1441	141.421	2.28254	7.21803	1.73359	3.73490	8.04660	.191939
5.22	27.2484	142.237	2.28473	7.22496	1.73470	3.73729	8.05175	.191571
5.23	27.3529	143.056	2.28692	7.23187	1.73580	3.73968	8.05689	.191205
5.24	27.4576	143.878	2.28910	7.23878	1.73691	3.74206	8.06202	.190840
5.25	27.5625	144.703	2.29129	7.24569	1.73801	3.74443	8.06714	.190476
5.26	27.6676	145.532	2.29347	7.25259	1.73912	3.74681	8.07226	.190114
5.27	27.7729	146.363	2.29565	7.25948	1.74022	3.74918	8.07737	.189753
5.28	27.8784	147.198	2.29783	7.26636	1.74132	3.75158	8.08248	.189394
5.29	27.9841	148.036	2.30000	7.27324	1.74242	3.75392	8.08758	.189036
5.30	28.0900	148.877	2.30217	7.28011	1.74351	3.75629	8.09267	.188679
5.31	28.1961	149.721	2.30434	7.28697	1.74461	3.75865	8.09776	.188324
5.32	28.3024	150.569	2.30651	7.29383	1.74570	3.76100	8.10284	.187970
5.33	28.4089	151.419	2.30868	7.30068	1.74680	3.76336	8.10791	.187617
5.34	28.5156	152.273	2.31084	7.30753	1.74789	3.76571	8.11298	.187266
5.35	28.6225	153.130	2.31301	7.31437	1.74898	3.76806	8.11804	.186916
5.36	28.7296	153.991	2.31517	7.32120	1.75007	3.77041	8.12310	.186567
5.37	28.8369	154.854	2.31733	7.32803	1.75116	3.77275	8.12814	.186220
5.38	28.9444	155.721	2.31948	7.33485	1.75224	3.77509	8.13319	.185874
5.39	29.0521	156.591	2.32164	7.34166	1.75333	3.77740	8.13822	.185529
5.40	29.1600	157.464	2.32379	7.34847	1.75441	3.77976	8.14325	.185185
5.41	29.2681	158.340	2.32594	7.35527	1.75549	3.78210	8.14828	.184843
5.42	29.3764	159.220	2.32809	7.36206	1.75657	3.78442	8.15329	.184502
5.43	29.4849	160.103	2.33024	7.36885	1.75765	3.78675	8.15831	.184162
5.44	29.5936	160.989	2.33238	7.37564	1.75873	3.78907	8.16331	.183824
5.45	29.7025	161.879	2.33452	7.38241	1.75981	3.79139	8.16831	.183486
5.46	29.8116	162.771	2.33666	7.38918	1.76088	3.79371	8.17330	.183150
5.47	29.9209	163.667	2.33880	7.39594	1.76196	3.79603	8.17829	.182815
5.48	30.0304	164.567	2.34094	7.40270	1.76303	3.79834	8.18327	.182482
5.49	30.1401	165.469	2.34307	7.40945	1.76410	3.80065	8.18824	.182149
5.50	30.2500	166.375	2.34521	7.41620	1.76517	3.80295	8.19321	.181818

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
5.51	30.3601	167.284	2.34734	7.42294	1.76624	3.80526	8.19818	.181488
5.52	30.4704	168.197	2.34947	7.42967	1.76731	3.80756	8.20313	.181159
5.53	30.5809	169.112	2.35160	7.43640	1.76838	3.80986	8.20808	.180832
5.54	30.6916	170.031	2.35372	7.44312	1.76944	3.80115	8.21303	.180505
5.55	30.8025	170.954	2.35584	7.44983	1.77051	3.81444	8.21797	.180180
5.56	30.9136	171.880	2.35797	7.45654	1.77157	3.81673	8.22290	.179856
5.57	31.0249	172.809	2.36008	7.46324	1.77263	3.81902	8.22783	.179533
5.58	31.1364	173.741	2.36220	7.46994	1.77369	3.82130	8.23275	.179212
5.59	31.2481	174.677	2.36432	7.47663	1.77475	3.82358	8.23766	.178891
5.60	31.3600	175.616	2.36643	7.48331	1.77581	3.82586	8.24257	.178571
5.61	31.4721	176.558	2.36854	7.48999	1.77686	3.82814	8.24747	.178253
5.62	31.5844	177.504	2.37065	7.49667	1.77792	3.83041	8.25237	.177936
5.63	31.6969	178.454	2.37276	7.50333	1.77897	3.83268	8.25726	.177620
5.64	31.8096	179.406	2.37487	7.50999	1.78003	3.83495	8.26215	.177305
5.65	31.9225	180.362	2.37697	7.51665	1.78108	3.83721	8.26703	.176991
5.66	32.0356	181.321	2.37908	7.52330	1.78213	3.83948	8.27190	.176678
5.67	32.1489	182.284	2.38118	7.52994	1.78318	3.84174	8.27677	.176367
5.68	32.2624	183.250	2.38328	7.53658	1.78422	3.84400	8.28164	.176056
5.69	32.3761	184.220	2.38537	7.54321	1.78527	3.84625	8.28649	.175747
5.70	32.4900	185.193	2.38747	7.54983	1.78632	3.84850	8.29134	.175439
5.71	32.6041	186.169	2.38956	7.55645	1.78736	3.85075	8.29619	.175131
5.72	32.7184	187.149	2.39165	7.56307	1.78840	3.85300	8.30103	.174825
5.73	32.8329	188.133	2.39374	7.56968	1.78944	3.85524	8.30587	.174520
5.74	32.9476	189.119	2.39583	7.57628	1.79048	3.85748	8.31069	.174216
5.75	33.0625	190.109	2.39792	7.58288	1.79152	3.85972	8.31552	.173913
5.76	33.1776	191.103	2.40000	7.58947	1.79256	3.86196	8.32034	.173611
5.77	33.2929	192.100	2.40208	7.59605	1.79360	3.86419	8.32515	.173310
5.78	33.4084	193.101	2.40416	7.60263	1.79463	3.86642	8.32995	.173010
5.79	33.5241	194.105	2.40624	7.60920	1.79567	3.86865	8.33476	.172712
5.80	33.6400	195.112	2.40832	7.61577	1.79670	3.87088	8.33955	.172414
5.81	33.7561	196.123	2.41039	7.62234	1.79773	3.87310	8.34434	.172117
5.82	33.8724	197.137	2.41247	7.62889	1.79876	3.87532	8.34913	.171821
5.83	33.9889	198.155	2.41454	7.63544	1.79979	3.87754	8.35390	.171527
5.84	34.1056	199.177	2.41661	7.64199	1.80082	3.87975	8.35868	.171233
5.85	34.2225	200.202	2.41868	7.64853	1.80185	3.88197	8.36345	.170940
5.86	34.3396	201.230	2.42074	7.65506	1.80288	3.88418	8.36821	.170649
5.87	34.4569	202.262	2.42281	7.66159	1.80390	3.88639	8.37297	.170358
5.88	34.5744	203.297	2.42487	7.66812	1.80492	3.88859	8.37772	.170068
5.89	34.6921	204.336	2.42693	7.67463	1.80595	3.89082	8.38247	.169779
5.90	34.8100	205.379	2.42899	7.68115	1.80697	3.89300	8.38721	.169492
5.91	34.9281	206.425	2.43105	7.68765	1.80799	3.89520	8.39194	.169205
5.92	35.0464	207.475	2.43311	7.69415	1.80901	3.89739	8.39667	.168919
5.93	35.1649	208.528	2.43516	7.70065	1.81003	3.89958	8.40140	.168634
5.94	35.2836	209.585	2.43721	7.70714	1.81104	3.90177	8.40612	.168350
5.95	35.4025	210.645	2.43926	7.71362	1.81206	3.90396	8.41083	.168067
5.96	35.5216	211.709	2.44131	7.72010	1.81307	3.90615	8.41554	.167785
5.97	35.6409	212.776	2.44336	7.72658	1.81409	3.90833	8.42025	.167504
5.98	35.7604	213.847	2.44540	7.73305	1.81510	3.91051	8.42494	.167224
5.99	35.8801	214.922	2.44745	7.73951	1.81611	3.91269	8.42964	.166945
6.00	36.0000	216.000	2.44949	7.74597	1.81712	3.91487	8.43433	.166667

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
6.01	36.1201	217.082	2.45153	7.75342	1.81813	3.91704	8.43901	.166389
6.02	36.2404	218.167	2.45357	7.75887	1.81914	3.91921	8.44369	.166113
6.03	36.3609	219.256	2.45561	7.76431	1.82014	3.92138	8.44836	.165838
6.04	36.4816	220.349	2.45764	7.77174	1.82115	3.92355	8.45303	.165563
6.05	36.6025	221.445	2.45967	7.77817	1.82215	3.92571	8.45769	.165289
6.06	36.7236	222.545	2.46171	7.78460	1.82316	3.92787	8.46235	.165017
6.07	36.8449	223.649	2.46374	7.79102	1.82416	3.93003	8.46700	.164745
6.08	36.9664	224.756	2.46577	7.79744	1.82516	3.93219	8.47165	.164474
6.09	37.0881	225.867	2.46779	7.80385	1.82616	3.93434	8.47629	.164204
6.10	37.2100	226.981	2.46982	7.81025	1.82716	3.93650	8.48093	.163934
6.11	37.3321	228.099	2.47184	7.81665	1.82816	3.93865	8.48556	.163666
6.12	37.4544	229.221	2.47386	7.82304	1.82915	3.94079	8.49018	.163399
6.13	37.5769	230.346	2.47588	7.82943	1.83015	3.94294	8.49481	.163132
6.14	37.6996	231.476	2.47790	7.83582	1.83115	3.94508	8.49942	.162866
6.15	37.8225	232.608	2.47992	7.84219	1.83214	3.94722	8.50404	.162602
6.16	37.9456	233.745	2.48193	7.84857	1.83313	3.94936	8.50864	.162338
6.17	38.0689	234.885	2.48395	7.85493	1.83412	3.95150	8.51324	.162075
6.18	38.1924	236.029	2.48596	7.86130	1.83511	3.95363	8.51784	.161812
6.19	38.3161	237.177	2.48797	7.86766	1.83610	3.95576	8.52243	.161551
6.20	38.4400	238.328	2.48998	7.87401	1.83709	3.95789	8.52702	.161290
6.21	38.5641	239.483	2.49199	7.88036	1.83808	3.96002	8.53160	.161031
6.22	38.6884	240.642	2.49399	7.88670	1.83906	3.96214	8.53618	.160772
6.23	38.8129	241.804	2.49600	7.89303	1.84005	3.96426	8.54075	.160514
6.24	38.9376	242.971	2.49800	7.89937	1.84103	3.96639	8.54532	.160256
6.25	39.0625	244.141	2.50000	7.90569	1.84202	3.96850	8.54988	.160000
6.26	39.1876	245.314	2.50200	7.91202	1.84300	3.97062	8.55444	.159744
6.27	39.3129	246.492	2.50400	7.91833	1.84398	3.97273	8.55899	.159490
6.28	39.4384	247.673	2.50599	7.92465	1.84496	3.97484	8.56354	.159236
6.29	39.5641	248.858	2.50799	7.93095	1.84594	3.97695	8.56808	.158983
6.30	39.6900	250.047	2.50998	7.93725	1.84691	3.97906	8.57262	.158730
6.31	39.8161	251.240	2.51197	7.94355	1.84789	3.98116	8.57715	.158479
6.32	39.9424	252.436	2.51396	7.94984	1.84887	3.98326	8.58168	.158228
6.33	40.0689	253.636	2.51595	7.95613	1.84984	3.98536	8.58620	.157978
6.34	40.1956	254.840	2.51794	7.96241	1.85082	3.98746	8.59072	.157729
6.35	40.3225	256.048	2.51992	7.96869	1.85179	3.98956	8.59524	.157480
6.36	40.4496	257.259	2.52190	7.97496	1.85276	3.99165	8.59975	.157233
6.37	40.5769	258.475	2.52389	7.98123	1.85373	3.99374	8.60425	.156986
6.38	40.7044	259.694	2.52587	7.98749	1.85470	3.99583	8.60875	.156740
6.39	40.8321	260.917	2.52784	7.99375	1.85567	3.99792	8.61325	.156495
6.40	40.9600	262.144	2.52982	8.00000	1.85664	4.00000	8.61774	.156250
6.41	41.0881	263.375	2.53180	8.00625	1.85760	4.00208	8.62222	.156006
6.42	41.2164	264.609	2.53377	8.01249	1.85857	4.00416	8.62671	.155763
6.43	41.3449	265.848	2.53574	8.01873	1.85953	4.00624	8.63118	.155521
6.44	41.4736	267.090	2.53772	8.02496	1.86050	4.00832	8.63566	.155280
6.45	41.6025	268.336	2.53969	8.03119	1.86146	4.01039	8.64012	.155039
6.46	41.7316	269.586	2.54165	8.03741	1.86242	4.01246	8.64459	.154799
6.47	41.8609	270.840	2.54362	8.04363	1.86338	4.01453	8.64904	.154560
6.48	41.9904	272.098	2.54558	8.04984	1.86434	4.01660	8.65350	.154321
6.49	42.1201	273.359	2.54755	8.05605	1.86530	4.01866	8.65795	.154083
6.50	42.2500	274.625	2.54951	8.06226	1.86626	4.02073	8.66239	.153846

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
6.51	42.3801	275.894	2.55147	8.06846	1.86721	4.02279	8.66683	.153610
6.52	42.5104	277.168	2.55343	8.07465	1.86817	4.02485	8.67127	.153374
6.53	42.6409	278.445	2.55539	8.08084	1.86912	4.02690	8.67570	.153139
6.54	42.7716	279.726	2.55734	8.08703	1.87008	4.02896	8.68012	.152905
6.55	42.9025	281.011	2.55930	8.09321	1.87103	4.03101	8.68455	.152672
6.56	43.0336	282.300	2.56125	8.09938	1.87198	4.03306	8.68896	.152439
6.57	43.1649	283.593	2.56320	8.10555	1.87293	4.03511	8.69338	.152207
6.58	43.2964	284.890	2.56515	8.11172	1.87388	4.03715	8.69778	.151976
6.59	43.4281	286.191	2.56710	8.11788	1.87483	4.03920	8.70219	.151745
6.60	43.5600	287.496	2.56905	8.12404	1.87578	4.04124	8.70659	.151515
6.61	43.6921	288.805	2.57099	8.13019	1.87672	4.04328	8.71098	.151286
6.62	43.8244	290.118	2.57294	8.13634	1.87767	4.04532	8.71537	.151057
6.63	43.9569	291.434	2.57488	8.14248	1.87862	4.04735	8.71976	.150830
6.64	44.0896	292.755	2.57682	8.14862	1.87956	4.04939	8.72414	.150602
6.65	44.2225	294.080	2.57876	8.15475	1.88050	4.05142	8.72852	.150376
6.66	44.3556	295.408	2.58070	8.16088	1.88144	4.05345	8.73289	.150150
6.67	44.4889	296.741	2.58263	8.16701	1.88239	4.05548	8.73726	.149925
6.68	44.6224	298.078	2.58457	8.17313	1.88333	4.05750	8.74162	.149701
6.69	44.7561	299.418	2.58650	8.17924	1.88427	4.05953	8.74598	.149477
6.70	44.8900	300.763	2.58844	8.18535	1.88520	4.06155	8.75034	.149254
6.71	45.0241	302.112	2.59037	8.19146	1.88614	4.06357	8.75469	.149031
6.72	45.1584	303.464	2.59230	8.19756	1.88708	4.06558	8.75904	.148810
6.73	45.2929	304.821	2.59422	8.20366	1.88801	4.06760	8.76338	.148588
6.74	45.4276	306.182	2.59615	8.20975	1.88895	4.06961	8.76772	.148368
6.75	45.5625	307.547	2.59808	8.21584	1.88988	4.07163	8.77205	.148148
6.76	45.6976	308.916	2.60000	8.22192	1.89081	4.07364	8.77638	.147929
6.77	45.8329	310.289	2.60192	8.22800	1.89175	4.07564	8.78071	.147711
6.78	45.9684	311.666	2.60384	8.23408	1.89268	4.07765	8.78503	.147493
6.79	46.1041	313.047	2.60576	8.24015	1.89361	4.07965	8.78935	.147275
6.80	46.2400	314.432	2.60768	8.24621	1.89454	4.08166	8.79366	.147059
6.81	46.3761	315.821	2.60960	8.25227	1.89546	4.08365	8.79797	.146843
6.82	46.5124	317.215	2.61151	8.25833	1.89639	4.08565	8.80227	.146628
6.83	46.6489	318.612	2.61343	8.26438	1.89732	4.08765	8.80657	.146413
6.84	46.7856	320.014	2.61534	8.27043	1.89824	4.08964	8.81087	.146199
6.85	46.9225	321.419	2.61725	8.27647	1.89917	4.09164	8.81516	.145985
6.86	47.0596	322.829	2.61916	8.28251	1.90009	4.09362	8.81945	.145773
6.87	47.1969	324.243	2.62107	8.28855	1.90102	4.09561	8.82373	.145560
6.88	47.3344	325.661	2.62298	8.29458	1.90194	4.09760	8.82801	.145349
6.89	47.4721	327.083	2.62488	8.30060	1.90286	4.09958	8.83229	.145138
6.90	47.6100	328.509	2.62679	8.30662	1.90378	4.10157	8.83656	.144928
6.91	47.7481	329.939	2.62869	8.31264	1.90470	4.10355	8.84082	.144718
6.92	47.8864	331.374	2.63059	8.31865	1.90562	4.10552	8.84509	.144509
6.93	48.0249	332.813	2.63249	8.32466	1.90653	4.10750	8.84934	.144300
6.94	48.1636	334.255	2.63439	8.33067	1.90745	4.10948	8.85360	.144092
6.95	48.3025	335.702	2.63629	8.33667	1.90837	4.11145	8.85785	.143885
6.96	48.4416	337.154	2.63818	8.34266	1.90928	4.11342	8.86210	.143678
6.97	48.5809	338.609	2.64008	8.34865	1.91019	4.11539	8.86634	.143472
6.98	48.7204	340.068	2.64197	8.35464	1.91111	4.11736	8.87058	.143267
6.99	48.8601	341.532	2.64386	8.36062	1.91202	4.11932	8.87481	.143062
7.00	49.0000	343.000	2.64575	8.36660	1.91293	4.12129	8.87904	.142857

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
7.01	49.1401	344.472	2.64764	8.37257	1.91384	4.12325	8.88327	.142653
7.02	49.2804	345.948	2.64953	8.37854	1.91475	4.12521	8.88749	.142450
7.03	49.4209	347.429	2.65141	8.38451	1.91566	4.12716	8.89171	.142248
7.04	49.5616	348.914	2.65330	8.39047	1.91657	4.12912	8.89592	.142046
7.05	49.7025	350.403	2.65518	8.39643	1.91747	4.13107	8.90013	.141844
7.06	49.8436	351.896	2.65707	8.40238	1.91838	4.13303	8.90434	.141643
7.07	49.9849	353.393	2.65895	8.40833	1.91929	4.13498	8.90854	.141443
7.08	50.1264	354.895	2.66083	8.41427	1.92019	4.13695	8.91274	.141243
7.09	50.2681	356.401	2.66271	8.42021	1.92109	4.13887	8.91693	.141044
7.10	50.4100	357.911	2.66458	8.42615	1.92200	4.14082	8.92112	.140845
7.11	50.5521	359.425	2.66646	8.43208	1.92290	4.14276	8.92531	.140647
7.12	50.6944	360.944	2.66833	8.43801	1.92380	4.14470	8.92949	.140449
7.13	50.8369	362.467	2.67021	8.44393	1.92470	4.14664	8.93367	.140253
7.14	50.9796	363.994	2.67208	8.44985	1.92560	4.14858	8.93784	.140056
7.15	51.1225	365.526	2.67395	8.45577	1.92650	4.15051	8.94201	.139860
7.16	51.2656	367.062	2.67582	8.46168	1.92740	4.15245	8.94618	.139665
7.17	51.4089	368.602	2.67769	8.46759	1.92829	4.15438	8.95034	.139470
7.18	51.5524	370.146	2.67955	8.47349	1.92919	4.15631	8.95450	.139276
7.19	51.6961	371.695	2.68142	8.47939	1.93008	4.15824	8.95866	.139082
7.20	51.8400	373.248	2.68328	8.48528	1.93098	4.16017	8.96281	.138889
7.21	51.9841	374.805	2.68514	8.49117	1.93187	4.16209	8.96696	.138696
7.22	52.1284	376.367	2.68701	8.49706	1.93277	4.16402	8.97110	.138504
7.23	52.2729	377.933	2.68887	8.50294	1.93366	4.16594	8.97524	.138313
7.24	52.4176	379.503	2.69072	8.50882	1.93455	4.16786	8.97938	.138122
7.25	52.5625	381.078	2.69258	8.51469	1.93544	4.16978	8.98351	.137931
7.26	52.7076	382.657	2.69444	8.52056	1.93633	4.17169	8.98764	.137741
7.27	52.8529	384.241	2.69629	8.52643	1.93722	4.17361	8.99176	.137552
7.28	52.9984	385.828	2.69815	8.53229	1.93810	4.17552	8.99588	.137363
7.29	53.1441	387.420	2.70000	8.53815	1.93899	4.17743	9.00000	.137174
7.30	53.2900	389.017	2.70185	8.54400	1.93988	4.17934	9.00411	.136986
7.31	53.4361	390.618	2.70370	8.54985	1.94076	4.18125	9.00822	.136799
7.32	53.5824	392.223	2.70555	8.55570	1.94165	4.18315	9.01233	.136612
7.33	53.7289	393.833	2.70740	8.56154	1.94253	4.18506	9.01643	.136426
7.34	53.8756	395.447	2.70924	8.56738	1.94341	4.18696	9.02053	.136240
7.35	54.0225	397.065	2.71109	8.57321	1.94430	4.18886	9.02462	.136054
7.36	54.1696	398.688	2.71293	8.57904	1.94518	4.19076	9.02871	.135870
7.37	54.3169	400.316	2.71477	8.58487	1.94606	4.19266	9.03280	.135685
7.38	54.4644	401.947	2.71662	8.59069	1.94694	4.19455	9.03689	.135501
7.39	54.6121	403.583	2.71846	8.59651	1.94782	4.19644	9.04097	.135318
7.40	54.7600	405.224	2.72029	8.60233	1.94870	4.19834	9.04504	.135135
7.41	54.9081	406.869	2.72213	8.60814	1.94957	4.20023	9.04911	.134953
7.42	55.0564	408.518	2.72397	8.61394	1.95045	4.20212	9.05318	.134771
7.43	55.2049	410.172	2.72580	8.61974	1.95132	4.20400	9.05725	.134590
7.44	55.3536	411.831	2.72764	8.62554	1.95220	4.20589	9.06131	.134409
7.45	55.5025	413.494	2.72947	8.63134	1.95307	4.20777	9.06537	.134228
7.46	55.6516	415.161	2.73130	8.63713	1.95395	4.20965	9.06942	.134048
7.47	55.8009	416.833	2.73313	8.64292	1.95482	4.21153	9.07347	.133869
7.48	55.9504	418.509	2.73496	8.64870	1.95569	4.21341	9.07752	.133690
7.49	56.1001	420.190	2.73679	8.65448	1.95656	4.21529	9.08156	.133511
7.50	56.2500	421.875	2.73861	8.66025	1.95743	4.21716	9.08560	.133333

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
7.51	56.4001	423.565	2.74044	8.66603	1.95830	4.21904	9.08964	.133156
7.52	56.5504	425.259	2.74226	8.67179	1.95917	4.22091	9.09367	.132979
7.53	56.7009	426.958	2.74408	8.67756	1.96004	4.22278	9.09770	.132802
7.54	56.8516	428.661	2.74591	8.68332	1.96091	4.22465	9.10173	.132626
7.55	57.0025	430.369	2.74773	8.68907	1.96177	4.22651	9.10575	.132450
7.56	57.1536	432.081	2.74955	8.69483	1.96264	4.22838	9.10977	.132275
7.57	57.3049	433.798	2.75136	8.70057	1.96350	4.23024	9.11378	.132100
7.58	57.4564	435.520	2.75318	8.70632	1.96437	4.23210	9.11779	.131926
7.59	57.6081	437.245	2.75500	8.71206	1.96523	4.23396	9.12180	.131752
7.60	57.7600	438.976	2.75681	8.71780	1.96610	4.23582	9.12581	.131579
7.61	57.9121	440.711	2.75862	8.72353	1.96696	4.23768	9.12981	.131406
7.62	58.0644	442.451	2.76043	8.72926	1.96782	4.23954	9.13380	.131234
7.63	58.2169	444.195	2.76225	8.73499	1.96868	4.24139	9.13780	.131062
7.64	58.3696	445.994	2.76405	8.74071	1.96954	4.24324	9.14179	.130890
7.65	58.5225	447.637	2.76586	8.74643	1.97040	4.24509	9.14577	.130719
7.66	58.6756	449.455	2.76767	8.75214	1.97126	4.24694	9.14976	.130548
7.67	58.8289	451.218	2.76948	8.75785	1.97211	4.24879	9.15374	.130378
7.68	58.9824	452.985	2.77128	8.76356	1.97297	4.25063	9.15771	.130208
7.69	59.1361	454.757	2.77308	8.76926	1.97383	4.25248	9.16169	.130039
7.70	59.2900	456.533	2.77489	8.77496	1.97468	4.25432	9.16566	.129870
7.71	59.4441	458.314	2.77669	8.78066	1.97554	4.25616	9.16962	.129702
7.72	59.5984	460.100	2.77849	8.78635	1.97639	4.25800	9.17359	.129534
7.73	59.7529	461.890	2.78029	8.79204	1.97724	4.25984	9.17754	.129366
7.74	59.9076	463.685	2.78209	8.79773	1.97809	4.26168	9.18150	.129199
7.75	60.0625	465.484	2.78388	8.80341	1.97895	4.26351	9.18545	.129032
7.76	60.2176	467.289	2.78568	8.80909	1.97980	4.26534	9.18940	.128866
7.77	60.3729	469.097	2.78747	8.81476	1.98065	4.26717	9.19335	.128700
7.78	60.5284	470.911	2.78927	8.82043	1.98150	4.26900	9.19729	.128535
7.79	60.6841	472.729	2.79106	8.82610	1.98234	4.27083	9.20123	.128370
7.80	60.8400	474.552	2.79285	8.83176	1.98319	4.27266	9.20516	.128205
7.81	60.9961	476.380	2.79464	8.83742	1.98404	4.27448	9.20910	.128041
7.82	61.1524	478.212	2.79643	8.84308	1.98489	4.27631	9.21303	.127877
7.83	61.3089	480.049	2.79821	8.84873	1.98573	4.27813	9.21695	.127714
7.84	61.4656	481.890	2.80000	8.85438	1.98658	4.27995	9.22087	.127551
7.85	61.6225	483.737	2.80179	8.86002	1.98742	4.28177	9.22479	.127389
7.86	61.7796	485.588	2.80357	8.86566	1.98826	4.28359	9.22871	.127227
7.87	61.9369	487.443	2.80535	8.87130	1.98911	4.28540	9.23262	.127065
7.88	62.0944	489.304	2.80713	8.87694	1.98995	4.28722	9.23653	.126904
7.89	62.2521	491.169	2.80891	8.88257	1.99079	4.28903	9.24043	.126743
7.90	62.4100	493.039	2.81069	8.88819	1.99163	4.29084	9.24433	.126582
7.91	62.5681	494.914	2.81247	8.89382	1.99247	4.29265	9.24823	.126422
7.92	62.7264	496.793	2.81425	8.89944	1.99331	4.29446	9.25213	.126263
7.93	62.8849	498.677	2.81603	8.90505	1.99415	4.29627	9.25602	.126103
7.94	63.0436	500.566	2.81780	8.91067	1.99499	4.29807	9.25991	.125945
7.95	63.2025	502.460	2.81957	8.91628	1.99582	4.29987	9.26380	.125786
7.96	63.3616	504.358	2.82135	8.92188	1.99666	4.30168	9.26768	.125628
7.97	63.5209	506.262	2.82312	8.92749	1.99750	4.30348	9.27156	.125471
7.98	63.6804	508.170	2.82489	8.93308	1.99833	4.30528	9.27544	.125313
7.99	63.8401	510.082	2.82666	8.93868	1.99917	4.30707	9.27931	.125156
8.00	64.0000	512.000	2.82843	8.94427	2.00000	4.30887	9.28318	.125000

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
8.01	64.1601	513.922	2.83019	8.94986	2.00083	4.31066	9.28704	.124844
8.02	64.3204	515.850	2.83196	8.95545	2.00167	4.31246	9.29091	.124688
8.03	64.4809	517.782	2.83373	8.96103	2.00250	4.31425	9.29477	.124533
8.04	64.6416	519.718	2.83549	8.96660	2.00333	4.31604	9.29862	.124378
8.05	64.8025	521.660	2.83725	8.97218	2.00416	4.31783	9.30248	.124224
8.06	64.9636	523.607	2.83901	8.97775	2.00499	4.31961	9.30633	.124070
8.07	65.1249	525.558	2.84077	8.98332	2.00582	4.32140	9.31018	.123916
8.08	65.2864	527.514	2.84253	8.98888	2.00664	4.32318	9.31402	.123762
8.09	65.4481	529.475	2.84429	8.99444	2.00747	4.32497	9.31786	.123609
8.10	65.6100	531.441	2.84605	9.00000	2.00830	4.32675	9.32170	.123457
8.11	65.7721	533.412	2.84781	9.00555	2.00912	4.32853	9.32553	.123305
8.12	65.9344	535.387	2.84956	9.01110	2.00995	4.33031	9.32936	.123153
8.13	66.0969	537.368	2.85132	9.01665	2.01078	4.33208	9.33319	.123001
8.14	66.2596	539.353	2.85307	9.02219	2.01160	4.33386	9.33702	.122850
8.15	66.4225	541.343	2.85482	9.02774	2.01242	4.33563	9.34084	.122699
8.16	66.5856	543.338	2.85657	9.03327	2.01325	4.33741	9.34466	.122549
8.17	66.7489	545.339	2.85832	9.03881	2.01407	4.33918	9.34847	.122399
8.18	66.9124	547.343	2.86007	9.04434	2.01489	4.34095	9.35229	.122249
8.19	67.0761	549.353	2.86182	9.04986	2.01571	4.34272	9.35610	.122100
8.20	67.2400	551.368	2.86356	9.05539	2.01653	4.34448	9.35990	.121951
8.21	67.4041	553.388	2.86531	9.06091	2.01735	4.34625	9.36370	.121803
8.22	67.5684	555.412	2.86705	9.06642	2.01817	4.34801	9.36751	.121655
8.23	67.7329	557.442	2.86880	9.07193	2.01899	4.34977	9.37130	.121507
8.24	67.8976	559.476	2.87054	9.07744	2.01980	4.35153	9.37510	.121359
8.25	68.0625	561.516	2.87228	9.08295	2.02062	4.35329	9.37889	.121212
8.26	68.2276	563.560	2.87402	9.08845	2.02144	4.35505	9.38268	.121065
8.27	68.3929	565.609	2.87576	9.09395	2.02225	4.35681	9.38646	.120919
8.28	68.5584	567.664	2.87750	9.09945	2.02307	4.35856	9.39024	.120773
8.29	68.7241	569.723	2.87924	9.10494	2.02388	4.36032	9.39402	.120627
8.30	68.8900	571.787	2.88097	9.11043	2.02469	4.36207	9.39780	.120482
8.31	69.0561	573.856	2.88271	9.11592	2.02551	4.36382	9.40157	.120337
8.32	69.2224	575.930	2.88444	9.12140	2.02632	4.36557	9.40534	.120192
8.33	69.3889	578.010	2.88617	9.12688	2.02713	4.36732	9.40911	.120048
8.34	69.5556	580.094	2.88791	9.13236	2.02794	4.36907	9.41287	.119904
8.35	69.7225	582.183	2.88964	9.13783	2.02875	4.37081	9.41663	.119761
8.36	69.8896	584.277	2.89137	9.14330	2.02956	4.37255	9.42039	.119617
8.37	70.0569	586.376	2.89310	9.14877	2.03037	4.37430	9.42414	.119474
8.38	70.2244	588.480	2.89482	9.15423	2.03118	4.37604	9.42789	.119332
8.39	70.3921	590.590	2.89655	9.15969	2.03199	4.37778	9.43164	.119190
8.40	70.5600	592.704	2.89828	9.16515	2.03279	4.37952	9.43539	.119048
8.41	70.7281	594.823	2.90000	9.17061	2.03360	4.38126	9.43913	.118906
8.42	70.8964	596.948	2.90172	9.17606	2.03440	4.38299	9.44287	.118765
8.43	71.0649	599.077	2.90345	9.18150	2.03521	4.38473	9.44661	.118624
8.44	71.2336	601.212	2.90517	9.18695	2.03601	4.38646	9.45034	.118483
8.45	71.4025	603.351	2.90689	9.19239	2.03682	4.38819	9.45407	.118343
8.46	71.5716	605.496	2.90861	9.19783	2.03762	4.38992	9.45780	.118203
8.47	71.7409	607.645	2.91033	9.20326	2.03842	4.39165	9.46152	.118064
8.48	71.9104	609.800	2.91204	9.20869	2.03923	4.39338	9.46525	.117925
8.49	72.0801	611.960	2.91376	9.21412	2.04003	4.39511	9.46897	.117786
8.50	72.2500	614.125	2.91548	9.21954	2.04083	4.39683	9.47268	.117647

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
8.51	72.4201	616.295	2.91719	9.22497	2.04163	4.39855	9.47640	.117509
8.52	72.5904	618.470	2.91890	9.23038	2.04243	4.40028	9.48011	.117371
8.53	72.7609	620.650	2.92062	9.23580	2.04323	4.40200	9.48381	.117233
8.54	72.9316	622.836	2.92233	9.24121	2.04402	4.40372	9.48752	.117096
8.55	73.1025	625.026	2.92404	9.24662	2.04482	4.40543	9.49122	.116959
8.56	73.2736	627.222	2.92575	9.25203	2.04562	4.40715	9.49492	.116822
8.57	73.4449	629.423	2.92746	9.25743	2.04641	4.40887	9.49861	.116686
8.58	73.6164	631.629	2.92916	9.26283	2.04721	4.41058	9.50231	.116550
8.59	73.7881	633.840	2.90387	9.26823	2.04801	4.41229	9.50600	.116414
8.60	73.9600	636.056	2.93258	9.27362	2.04880	4.41400	9.50969	.116279
8.61	74.1321	638.277	2.93428	9.27901	2.04959	4.41571	9.51337	.116144
8.62	74.3044	640.504	2.93598	9.28440	2.05039	4.41742	9.51705	.116009
8.63	74.4769	642.736	2.93769	9.28978	2.05118	4.41913	9.52073	.115875
8.64	74.6496	644.973	2.93939	9.29516	2.05197	4.42084	9.52441	.115741
8.65	74.8225	647.215	2.94109	9.30054	2.05276	4.42254	9.52808	.115607
8.66	74.9956	649.462	2.94279	9.30591	2.05355	4.42425	9.53175	.115473
8.67	75.1689	651.714	2.94449	9.31128	2.05434	4.42595	9.53542	.115340
8.68	75.3424	653.972	2.94618	9.31665	2.05513	4.42765	9.53908	.115207
8.69	75.5161	656.235	2.94788	9.32202	2.05592	4.42935	9.54274	.115075
8.70	75.6900	658.503	2.94958	9.32738	2.05671	4.43105	9.54640	.114943
8.71	75.8641	660.776	2.95127	9.33274	2.05750	4.43274	9.55006	.114811
8.72	76.0384	663.055	2.95296	9.33809	2.05828	4.43444	9.55371	.114679
8.73	76.2129	665.339	2.95466	9.34345	2.05907	4.43614	9.55736	.114548
8.74	76.3876	667.628	2.95635	9.34880	2.05986	4.43783	9.56101	.114417
8.75	76.5625	669.922	2.95804	9.35414	2.06064	4.43952	9.56466	.114286
8.76	76.7376	672.221	2.95973	9.35949	2.06143	4.44121	9.56830	.114155
8.77	76.9129	674.526	2.96142	9.36483	2.06221	4.44290	9.57194	.114025
8.78	77.0884	676.836	2.96311	9.37017	2.06299	4.44459	9.57557	.113895
8.79	77.2641	679.151	2.96479	9.37550	2.06378	4.44627	9.57921	.113766
8.80	77.4400	681.472	2.96648	9.38083	2.06456	4.44796	9.58284	.113636
8.81	77.6161	683.798	2.96816	9.38616	2.06534	4.44964	9.58647	.113507
8.82	77.7924	686.129	2.96985	9.39149	2.06612	4.45133	9.59009	.113379
8.83	77.9689	688.465	2.97153	9.39681	2.06690	4.45301	9.59372	.113250
8.84	78.1456	690.807	2.97321	9.40213	2.06768	4.45469	9.59734	.113122
8.85	78.3225	693.154	2.97489	9.40744	2.06846	4.45637	9.60095	.112994
8.86	78.4996	695.506	2.97658	9.41276	2.06924	4.45805	9.60457	.112867
8.87	78.6769	697.864	2.97825	9.41807	2.07002	4.45972	9.60818	.112740
8.88	78.8544	700.227	2.97993	9.42338	2.07080	4.46140	9.61179	.112613
8.89	79.0321	702.595	2.98161	9.42868	2.07157	4.46307	9.61540	.112486
8.90	79.2100	704.969	2.98329	9.43398	2.07235	4.46474	9.61900	.112360
8.91	79.3881	707.348	2.98496	9.43928	2.07313	4.46642	9.62260	.112233
8.92	79.5664	709.732	2.98664	9.44458	2.07390	4.46809	9 62620	.112108
8.93	79.7449	712.122	2.98831	9.44987	2.07468	4.46976	9.62980	.111982
8.94	79.9236	714.517	2.98998	9.45516	2.07545	4.47142	9.63339	.111857
8.95	80.1025	716.917	2.99166	9.46044	2.07622	4.47309	9.63698	.111732
8.96	80.2816	719.323	2.99333	9.46573	2.07700	4.47476	9.64057	.111607
8.97	80.4609	721.734	2.99500	9.47101	2.07777	4.47642	9.64415	.111483
8.98	80.6404	724.151	2.99666	9.47629	2.07854	4.47808	9.64774	.111359
8.99	80.8201	726.573	2.99833	9.48156	2.07931	4.47974	9.65132	.111235
9.00	81.0000	729.000	3.00000	9.48683	2.08008	4.48140	9.65489	.111111

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
9.01	81.1801	731.433	3.00167	9.49210	2.08085	4.48306	9.65847	.110988
9.02	81.3604	733.871	3.00333	9.49737	2.08162	4.48472	9.66204	.110865
9.03	81.5409	736.314	3.00500	9.50263	2.08239	4.48638	9.66561	.110742
9.04	81.7216	738.763	3.00666	9.50789	2.08316	4.48805	9.66918	.110620
9.05	81.9025	741.218	3.00832	9.51315	2.08393	4.48968	9.67274	.110497
9.06	82.0836	743.677	3.00998	9.51840	2.08470	4.49134	9.67630	.110375
9.07	82.2649	746.143	3.01164	9.52365	2.08546	4.49299	9.67986	.110254
9.08	82.4464	748.613	3.01330	9.52890	2.08623	4.49464	9.68342	.110132
9.09	82.6281	751.089	3.01496	9.53415	2.08699	4.49629	9.68697	.110011
9.10	82.8100	753.571	3.01662	9.53939	2.08776	4.49794	9.69052	.109890
9.11	82.9921	756.058	3.01828	9.54463	2.08852	4.49959	9.69407	.109770
9.12	83.1744	758.551	3.01993	9.54987	2.08929	4.50123	9.69762	.109649
9.13	83.3569	761.048	3.02159	9.55510	2.09005	4.50288	9.70116	.109529
9.14	83.5396	763.552	3.02324	9.56033	2.09081	4.50452	9.70470	.109409
9.15	83.7225	766.061	3.02490	9.56556	2.09158	4.50616	9.70824	.109290
9.16	83.9056	768.575	3.02655	9.57079	2.09234	4.50780	9.71177	.109170
9.17	84.0889	771.095	3.02820	9.57601	2.09310	4.50945	9.71531	.109051
9.18	84.2724	773.621	3.02985	9.58123	2.09386	4.51108	9.71884	.108933
9.19	84.4561	776.152	3.03150	9.58645	2.09462	4.51272	9.72236	.108814
9.20	84.6400	778.688	3.03315	9.59166	2.09538	4.51436	9.72589	.108696
9.21	84.8241	781.230	3.03480	9.59687	2.09614	4.51599	9.72941	.108578
9.22	85.0084	783.777	3.03645	9.60208	2.09690	4.51763	9.73293	.108460
9.23	85.1929	786.330	3.03809	9.60729	2.09765	4.51926	9.73645	.108342
9.24	85.3776	788.889	3.03974	9.61249	2.09841	4.52089	9.73996	.108225
9.25	85.5625	791.453	3.04138	9.61769	2.09917	4.52252	9.74348	.108108
9.26	85.7476	794.023	3.04302	9.62289	2.09992	4.52415	9.74699	.107991
9.27	85.9329	796.598	3.04467	9.62808	2.10068	4.52578	9.75049	.107875
9.28	86.1184	799.179	3.04631	9.63328	2.10144	4.52740	9.75400	.107759
9.29	86.3041	801.765	3.04795	9.63846	2.10219	4.52903	9.75750	.107643
9.30	86.4900	804.357	3.04959	9.64365	2.10294	4.53065	9.76100	.107527
9.31	86.6761	806.954	3.05123	9.64883	2.10370	4.53228	9.76450	.107411
9.32	86.8624	809.558	3.05287	9.65401	2.10445	4.53390	9.76799	.107296
9.33	87.0489	812.166	3.05450	9.65919	2.10520	4.53552	9.77148	.107181
9.34	87.2356	814.781	3.05614	9.66437	2.10595	4.53714	9.77497	.107066
9.35	87.4225	817.400	3.05778	9.66954	2.10671	4.53876	9.77846	.106952
9.36	87.6096	820.026	3.05941	9.67471	2.10746	4.54038	9.78195	.106838
9.37	87.7969	822.657	3.06105	9.67988	2.10821	4.54199	9.78543	.106724
9.38	87.9844	825.294	3.06268	9.68504	2.10896	4.54361	9.78891	.106610
9.39	88.1721	827.936	3.06431	9.69020	2.10971	4.54522	9.79239	.106496
9.40	88.3600	830.584	3.06594	9.69536	2.11045	4.54684	9.79586	.106383
9.41	88.5481	833.238	3.06757	9.70052	2.11120	4.54845	9.79933	.106270
9.42	88.7364	835.897	3.06920	9.70567	2.11195	4.55006	9.80280	.106157
9.43	88.9249	838.562	3.07083	9.71082	2.11270	4.55167	9.80627	.106045
9.44	89.1136	841.232	3.07246	9.71597	2.11344	4.55328	9.80974	.105932
9.45	89.3025	843.909	3.07409	9.72111	2.11419	4.55488	9.81320	.105820
9.46	89.4916	846.591	3.07571	9.72625	2.11494	4.55649	9.81666	.105708
9.47	89.6809	849.278	3.07734	9.73139	2.11568	4.55809	9.82012	.105597
9.48	89.8704	851.971	3.07896	9.73653	2.11642	4.55970	9.82357	.105485
9.49	90.0601	854.670	3.08058	9.74166	2.11717	4.56130	9.82703	.105374
9.50	90.2500	857.375	3.08221	9.74679	2.11791	4.56290	9.83048	.105263

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n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
9.51	90.4401	860.085	3.08383	9.75192	2.11865	4.56450	9.83392	.105158
9.52	90.6304	862.801	3.08545	9.75705	2.11940	4.56610	9.83737	.105042
9.53	90.8209	865.523	3.08707	9.76217	2.12014	4.56770	9.84081	.104932
9.54	91.0116	868.251	3.08869	9.76729	2.12088	4.56930	9.84425	.104822
9.55	91.2025	870.984	3.09031	9.77241	2.12162	4.57089	9.84769	.104712
9.56	91.3936	873.723	3.09192	9.77753	2.12236	4.57249	9.85113	.104603
9.57	91.5849	876.467	3.09354	9.78264	2.12310	4.57408	9.85456	104498
9.58	91.7764	879.218	3.09516	9.78775	2.12384	4.57568	9.85799	.104384
9.59	91.9681	881.974	3.09677	9.79285	2.12458	4.57727	9.86142	.104275
9.60	92.1600	884.736	3.09839	9.79796	2.12532	4.57886	9.86485	.104167
9.61	92.3521	887.504	3.10000	9.80306	2.12605	4.58045	9.86827	.104058
9.62	92.5444	890.277	3.10161	9.80816	2.12679	4.58203	9.87169	103950
9.63	92.7369	893.056	3.10322	9.81326	2.12753	4.58362	9.87511	.103842
9.64	92.9296	895.841	3.10483	9.81835	2.12826	4.58521	9.87853	103734
9.65	93.1225	898.632	3.10644	9.82344	2.12900	4.58679	9.88195	.103627
9.66	93.3156	901.429	3.10805	9.82853	2.12974	4.58838	9.88536	.103520
9.67	93.5089	904.231	3.10966	9.83362	2.13047	4.58996	9.88877	.103413
9.68	93.7024	907.039	3.11127	9.83870	2.13120	4.59154	9.89217	.103306
9.69	93.8961	909.853	3.11288	9.84378	2.13194	4.59312	9.89558	.103199
9.70	94.0900	912.673	3.11448	9.84886	2.13267	4.59470	9.89898	.103093
9.71	94.2841	915.499	3.11609	9.85393	2.13340	4.59628	9.90238	.102987
9.72	94.4784	918.330	3.11769	9.85901	2.13414	4.59786	9.90578	.102881
9.73	94.6729	921.167	3.11929	9.86408	2.13487	4.59943	9.90918	.102775
9.74	94.8676	924.010	3.12090	9.86914	2.13560	4.60101	9.91257	.102669
9.75	95.0625	926.859	3.12250	9.87421	2.13633	4.60258	9.91596	.102564
9.76	95.2576	929.714	3.12410	9.87927	2.13706	4.60416	9.91935	.102459
9.77	95.4529	932.575	3.12570	9.88433	2.13779	4.60573	9.92274	.102354
9.78	95.6484	935.441	3.12730	9.88939	2.13852	4.60730	9.92612	102250
9.79	95.8441	938.314	3.12890	9.89444	2.13925	4.60887	9.92950	.102145
9.80	96.0400	941.192	3.13050	9.89949	2.13997	4.61044	9.93288	.102041
9.81	96.2361	944.076	3.13209	9.90454	2.14070	4.61200	9.93626	.101937
9.82	96.4324	946.966	3.13369	9.90959	2.14143	4.61357	9.93964	.101833
9.83	96.6289	949.862	3.13528	9.91464	2.14216	4.61513	9.94301	.101729
9.84	96.8256	952.764	3.13688	9.91968	2.14288	4.61670	9.94638	.101626
9.85	97.0225	955.672	3.13847	9.92472	2.14361	4.61826	9.94975	.101523
9.86	97.2196	958.585	3.14006	9.92975	2.14433	4.61983	9.95311	.101420
9.87	97.4169	961.505	3.14166	9.93479	2.14506	4.62139	9.95648	.101317
9.88	97.6144	964.430	3.14325	9.93982	2.14578	4.62295	9.95984	.101215
9.89	97.8121	967.362	3.14484	9.94485	2.14651	4.62451	9.96320	.101112
9.90	98.0100	970.299	3.14643	9.94987	2.14723	4.62607	9.96655	.101010
9.91	98.2081	973.242	3.14802	9.95490	2.14795	4.62762	9.96991	.100908
9.92	98.4064	976.191	3.14960	9.95992	2.14867	4.62918	9.97326	.100807
9.93	98.6049	979.147	3.15119	9.96494	2.14940	4.63073	9.97661	.100705
9.94	98.8036	982.108	3.15278	9.96995	2.15012	4.63229	9.97996	.100604
9.95	99.0025	985.075	3.15436	9.97497	2.15084	4.63384	9.98331	.100503
9.96	99.2016	988.048	3.15595	9.97998	2.15156	4.63539	9.98665	.100402
9.97	99.4009	991.027	3.15753	9.98499	2.15228	4.63694	9.98999	.100301
9.98	99.6004	994.012	3 15911	9.98999	2.15300	4.63849	9.99333	.100200
9.99	99.8001	997.003	3.16070	9.99500	2.15372	4.64004	9.99667	.100100
10.00	100.000	1000.00	3.16228	10.0000	2.15443	4.64159	10.0000	.100000

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WEIGHTS AND MEASURES.

LINEAR MEASURE.

12	inches (in.)	= 1	foot	ft.
3	feet	= 1	yard	yd.
5.5	yards	= 1	rod	rd.
40	rods	= 1	furlong	fur.
8	furlongs	= 1	mile	mi.

in.	ft.	yd.	rd.	fur.	mi.
36 =	3 =	1			
198 =	16.5 =	5.5 =	1		
7,920 =	660 =	220 =	40 =	1	
63,360 =	5,280 =	1,760 =	320 =	8 =	1

SURVEYOR'S MEASURE.

7.92	inches	= 1 link	li.
25	links	= 1 rod	rd.
4 rods 100 links 66 feet		= 1 chain	ch.
80	chains	= 1 mile	mi.

1 mi. = 80 ch. = 320 rd. = 8,000 li. = 63,360 in.

SQUARE MEASURE.

144	square inches (sq. in.)	= 1	square foot	sq. ft.
9	square feet	= 1	square yard	sq. yd.
30¼	square yards	= 1	square rod	sq. rd.
160	square rods	= 1	acre	A.
640	acres	= 1	square mile	sq. mi.

sq. mi.	A.	sq. rd.	sq. yd.	sq. ft.	sq. in.
1 =	640 =	102,400 =	3,097,600 =	27,878,400 =	4,014,489,600

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SURVEYOR'S SQUARE MEASURE.

625 square links (sq. li.)	=	1 square rod	sq. rd.
16 square rods	=	1 square chain	sq. ch.
10 square chains	=	1 acre	A.
640 acres	=	1 square mile	sq. mi.
36 square miles (6 mi. square)	=	1 township	Tp.

1 sq. mi. = 640 A. = 6,400 sq. ch. = 102,400 sq. rd.
= 64,000,000 sq. li.

The acre contains 4,840 sq. yd., or 43,560 sq. ft., and in form of a square is 208.71 ft. on a side.

CUBIC MEASURE.

1,728 cubic inches (cu. in.)	=	1 cubic foot	cu. ft.
27 cubic feet	=	1 cubic yard	cu. yd.
128 cubic feet	=	1 cord	cd.
24¾ cubic feet	=	1 perch	P.

1 cu yd. = 27 cu. ft. = 46,656 cu. in.

MEASURE OF ANGLES OR ARCS.

60 seconds (″)	=	1 minute	′
60 minutes	=	1 degree	°
90 degrees	=	1 rt. angle or quadrant	□
360 degrees	=	1 circle	cir.

1 cir. = 360° = 21,600′ = 1,296,000″

AVOIRDUPOIS WEIGHT.

437.5 grains (gr.)	=	1 ounce	oz.
16 ounces	=	1 pound	lb.
100 pounds	=	1 hundredweight	cwt.
20 cwt., or 2,000 lb.	=	1 ton	T.

1 T. = 20 cwt. = 2,000 lb. = 32,000 oz. = 14,000,000 gr.

The avoirdupois pound contains 7,000 grains.

LONG TON TABLE.

16 ounces	=	1 pound	lb.
112 pounds	=	1 hundredweight	cwt.
20 cwt, or 2,240 lb.	=	1 ton	T.

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TROY WEIGHT.

24 grains (gr.) ..... = 1 pennyweight .....pwt.
20 pennyweights..... = 1 ounce .....oz.
12 ounces..... = 1 pound .....lb.

1 lb. = 12 oz. = 240 pwt. = 5,760 gr.

DRY MEASURE.

2 pints (pt.) ..... = 1 quart .....qt.
8 quarts ..... = 1 peck .....pk.
4 pecks..... = 1 bushel .....bu.

1 bu. = 4 pk. = 32 qt. = 64 pt.

The U. S. struck bushel contains 2,150.42 cu. in. = 1.2444 cu. ft. Its dimensions are, by law, 18½ in. in diameter and 8 in. deep. The heaped bushel is equal to 1¼ struck bushels, the cone being 6 in. high. The dry gallon contains 268.8 cu. in., being ¼ bu.

For approximations, the bushel may be taken at 1¼ cu. ft.; or a cubic foot may be considered ⅘ of a bushel.

The British bushel contains 2,218.19 cu. in. = 1.2837 cu. ft. = 1.032 U. S. bushels.

LIQUID MEASURE.

4 gills (gi.) ..... = 1 pint .....pt.
2 pints ..... = 1 quart .....qt.
4 quarts..... = 1 gallon .....gal.
31½ gallons..... = 1 barrel .....bbl.
2 barrels, or 63 gallons ..... = 1 hogshead .....hhd.

1 hhd. = 2 bbl. = 63 gal. = 252 qt. = 504 pt. = 2,016 gi.

The U. S. gallon contains 231 cu. in. = .134 cu. ft., nearly; or 1 cu. ft. contains 7.480 gal. The following cylinders contain the given measures very closely:

	Diam.	Height		Diam.	Height
Gill.....	1¾ in.	3 in.	Gallon	7 in.	6 in.
Pint	3½ in.	3 in.	8 gallons	14 in.	12 in.
Quart	3½ in.	6 in.	10 gallons	14 in.	15 in.

With water at its maximum density (weighing 62.425 lb. per cu. ft.), a gallon of pure water weighs 8.345 lb.

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For approximations, 1 cu. ft. of water is considered equal to 7½ gal., and 1 gal. as weighing 8⅓ lb.

The British imperial gallon, both liquid and dry, contains 277.274 cu. in. = .16046 cu. ft., and is equivalent to the volume of 10 lb. of pure water at 62° F. To reduce U. S. to British liquid gallons, divide by 1.2. Conversely, to convert British into U. S. liquid gallons, multiply by 1.2; or, increase the number of gallons ⅕.

MISCELLANEOUS TABLE.

12 articles	=	1 dozen.	20 quires	=	1 ream.
12 dozen	=	1 gross.	1 league	=	3 miles.
12 gross	=	1 great gross.	1 fathom	=	6 feet.
2 articles	=	1 pair.	1 hand	=	4 inches.
20 articles	=	1 score.	1 palm	=	3 inches.
24 sheets	=	1 quire.	1 span	=	9 inches.

1 knot (U. S.) = 6,086.07 ft. = 1⅛ miles (roughly).

1 meter = 3 feet 3⅜ inches (nearly).

THE METRIC SYSTEM.

The metric system is based on the meter, which, according to the U. S. Coast and Geodetic Survey Report of 1884, is equal to 39.370432 inches. The value commonly used is 39.37 inches, and is authorized by the U. S. government. The meter is defined as one ten-millionth the distance from the pole to the equator, measured on a meridian passing near Paris.

There are three principal units—the meter, the liter (pronounced lee-ter), and the gram, the units of length, capacity, and weight, respectively. Multiples of these units are obtained by prefixing to the names of the principal units the Greek words deca (10), hecto (100), and kilo (1,000); the submultiples, or divisions, are obtained by prefixing the Latin words deci ($\frac{1}{10}$), centi ($\frac{1}{100}$), and milli ($\frac{1}{1000}$). These prefixes form the key to the entire system. In the following tables, the abbreviations of the principal units of these submultiples begin with a small letter, while those of the multiples begin with a capital letter; they should always be written as here printed.

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MEASURES OF LENGTH.

10 millimeters (mm.)	=	1 centimeter	cm.
10 centimeters	=	1 decimeter	dm.
10 decimeters	=	1 meter	m.
10 meters	=	1 decameter	Dm.
10 decameters	=	1 hectometer	Hm.
10 hectometers	=	1 kilometer	Km.

MEASURES OF SURFACE (NOT LAND).

100 square millimeters (mm^2)	=	1 square centimeter	cm^2.
100 square centimeters	=	1 square decimeter	dm^2.
100 square decimeters	=	1 square meter	m^2.

MEASURES OF SURFACE (LAND).

1 square meter	=	1 centare	ca.
100 centares	=	1 are	A.
100 ares	=	1 hectare	Ha.
100 hectares	=	1 square kilometer	Km^2.

MEASURES OF VOLUME.

1,000 cubic millimeters (mm^3)	=	1 cubic centimeter	cm^3.
1,000 cubic centimeters	=	1 cubic decimeter	dm^3.
1,000 cubic decimeters	=	1 cubic meter	m^3.

MEASURES OF CAPACITY.

10 milliliters (ml.)	=	1 centiliter	cl.
10 centiliters	=	1 deciliter	dl.
10 deciliters	=	1 liter	l.
10 liters	=	1 decaliter	Dl.
10 decaliters	=	1 hectoliter	Hl.
10 hectoliters	=	1 kiloliter	Kl.

NOTE.—The liter is equal to 1 cubic decimeter.

MEASURES OF WEIGHT.

10 milligrams (mg.)	=	1 centigram	cg.
10 centigrams	=	1 decigram	dg.
10 decigrams	=	1 gram	g.
10 grams	=	1 decagram	Dg.
10 decagrams	=	1 hectogram	Hg.
10 hectograms	=	1 kilogram	Kg.
1,000 kilograms	=	1 ton	T.

NOTE.—The gram is the weight of 1 cubic centimeter of pure distilled water at a temperature of 39.2° F.; the kilogram is the weight of 1 liter of water; the ton is the weight of 1 cubic meter of water.

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CONVERSION TABLES.

By means of the tables on pages 8 and 9, metric measures can be converted into English, and *vice versa*, by simple addition. All the figures of the values given are not required, four or five digits being all that are commonly used; it is only in very exact calculations that all the digits are necessary. Using table, proceed as follows: Change 6,471.8 feet into meters. Any number, as 6,471.8, may be regarded as 6,000 + 400 + 70 + 1 + .8; also, 6,000 = 1,000 × 6; 400 = 100 × 4, etc. Hence, looking in the left-hand column of the upper table, page 39, for figure 6 (the first figure of the given number), we find opposite it in the third column, which is headed "Feet to Meters," the number 1.8287838. Now, using but five digits and increasing the fifth digit by 1 (since the next is greater than 5), we get 1.8288. In other words, 6 feet = 1.8288 meters; hence, 6,000 feet = 1,000 × 1.8288 = 1,828.8, simply moving the decimal point three places to the right. Likewise, 400 feet = 121.92 meters; 70 feet = 21.336 meters; 1 foot = .3048 meter, and .8 foot = .2438 meter. Adding as shown above, we get 1,972.6046 meters.

1,828.8
121.92
21.336
.3048
.2438
1,972.6046

Again, convert 19.635 kilos into pounds. The work should be perfectly clear from the explanation given above. The result is 43.2875 pounds.

22.046
19.8416
1.3228
.0661
.0110
43.2875

The only difficulty in applying these tables lies in locating the decimal point; it may always be found thus: If the figure considered lies to the left of the decimal point, count each figure in order, beginning with units (but calling unit's place zero), until the desired figure is reached, then move the decimal point to the *right* as many places as the figure being considered is to the left of the unit figure. Thus, in the first case above, 6 lies three places to the left of 1, which is in unit's place; hence, the decimal point is moved three places to the *right*. By exchanging the words "right" and "left," the statement will also apply to decimals. Thus, in the second case above, the 5 lies three places to the *right* of unit's place; hence, the decimal point in the number taken from the table is moved three places to the *left*.

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CONVERSION TABLE—ENGLISH MEASURES INTO METRIC.

English.	Metric. Inches to Meters.	Metric. Feet to Meters.	Metric. Pounds to Kilos.	Metric. Gallons to Liters.
1	.0253998	.3047973	.4535925	3.7853122
2	.0507996	.6095946	.9071850	7.5706244
3	.0761993	.9143919	1.3607775	11.3559366
4	.1015991	1.2191892	1.8143700	15.1412488
5	.1269989	1.5239865	2.2679625	18.9265610
6	.1523987	1.8287838	2.7215550	22.7118732
7	.1777984	2.1335811	3.1751475	26.4971854
8	.2031982	2.4383784	3.6287400	30.2824976
9	.2285980	2.7431757	4.0823325	34.0678098
10	.2539978	3.0479730	4.5359250	37.8531220

CONVERSION TABLE—ENGLISH MEASURES INTO METRIC.

English.	Metric. Square Inches to Square Meters.	Metric. Square Feet to Square Meters.	Metric. Cubic Feet to Cubic Meters.	Metric. Pounds per Square Inch to Kilo per Square Meter.
1	.000645150	.092901394	.028316094	703.08241
2	.001290300	.185802738	.056632188	1,406.16482
3	.001935450	.278704182	.084948282	2,109.24723
4	.002580600	.371605576	.113264376	2,812.32964
5	.003225750	.464506970	.141580470	3,515.41205
6	.003870900	.557408364	.169896564	4,218.49446
7	.004516050	.650309758	.198212658	4,921.57687
8	.005161200	.743211152	.226528752	5,624.65928
9	.005806350	.836112546	.254844846	6,327.74169
10	.006451500	.929013940	.283160940	7,030.82410

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CONVERSION TABLE—METRIC MEASURES INTO ENGLISH.

Metric.	English. Meters to Inches.	English. Meters to Feet.	English. Kilos to Pounds.	English. Liters to Gallons.
1	39.370432	3.2808693	2.2046223	.2641790
2	78.740864	6.5617386	4.4092447	.5283580
3	118.111296	9.8426079	6.6138670	.7925871
4	157.481728	13.1234772	8.8184894	1.0567161
5	196.852160	16.4043465	11.0231117	1.3208951
6	236.222592	19.6852158	13.2277340	1.5850741
7	275.593024	22.9660851	15.4323564	1.8492531
8	314.963456	26.2469544	17.6369787	2.1134322
9	354.333888	29.5278237	19.8416011	2.3776112
10	393.704320	32.8086930	22.0462234	2.6417902

CONVERSION TABLE—METRIC MEASURES INTO ENGLISH.

Metric.	English. Square Meters to Square Inches.	English. Square Meters to Square Feet.	English. Cubic Meters to Cubic Feet.	English. Kilos per Square Meter to Pounds per Square Inch.
1	1,550.03092	10.7641034	35.3156163	.001422310
2	3,100.06184	21.5282068	70.6312326	.002844620
3	4,650.09276	32.2923102	105.9468489	.004266930
4	6,200.12368	43.0564136	141.2624652	.005689240
5	7,750.15460	53.8205170	176.5780815	.007111550
6	9,300.18552	64.5846204	211.8936978	.008533860
7	10,850.21644	75.3487238	247.2093141	.009956170
8	12,400.24736	86.1128272	282.5249304	.001378480
9	13,950.27828	96.8769306	317.8405467	.012800790
10	15,500.30920	107.6410340	353.1561630	.014223100

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SPECIFIC GRAVITIES AND WEIGHTS.

The specific gravity of a solid or liquid body is the ratio between its weight and that of a like volume of distilled water. If the solid is of irregular shape, its specific gravity may be found by weighing it in air and in water; the loss of weight in water is the weight of an equal volume of water; hence, if W is the weight in air, and W' the weight in water, the specific gravity is $\frac{W}{W - W'}$.

The weight of water in various conditions is as follows:

Water, pure at 32° F. weighs 62.417 lb. per cu. ft.
Water, pure at 39° F. weighs 62.425 lb. per cu. ft.
Water, pure at 62° F. weighs 62.355 lb. per cu. ft.
Water, pure at 212° F. weighs 59.700 lb. per cu. ft.
Water, sea.....weighs 64.080 lb. per cu. ft.
Ice .....weighs 57.400 lb. per cu. ft.
Snow, fresh .....weighs 5 to 12 lb. per cu. ft.
Snow, wet.....weighs 15 to 50 lb. per cu. ft.

METALS.

Name of Metal.	Weight per Cu. In. Pounds.	Weight per Cu. Ft. Pounds.	Specific Gravity.
Aluminum.....	.096	166	2.66
Antimony	.242	418	6.70
Bismuth	.350	607	9.74
Brass, cast	.292	504	8.10
Brass, rolled	.303	524	8.40
Bronze (gun metal)	.305	529	8.50
Copper, cast	.314	542	8.70
Copper, rolled	.321	555	8.90
Gold, 24 carat	.694	1,204	19.26
Iron, cast	.260	450	7.21
Iron, wrought	.277	480	7.66
Lead, commercial	.410	710	11.38
Mercury, 60° F.	.489	846	13.58
Platinum	.779	1,342	21.50
Silver	.378	655	10.50
Steel.....	.283	490	7.85
Tin, cast	.265	459	7.35
Zinc	.253	437	7.00

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BUILDING MATERIALS, ETC.

Name of Material.	Weight per Cu. Ft. Pounds.	Specific Gravity.
Bluestone	160	2.56
Brick, pressed	150	2.40
Brick, common	125	2.00
Chalk	156	2.50
Charcoal	15–30	.24–.48
Clay, compact	119	1.90
Coke, loose	23–32	.37–.51
Coal, hard, solid	93.5	1.50
Coal, hard, broken	54	.865
Coal, soft, solid	84	1.35
Coal, soft, broken	50	.80
Concrete, cement	140	2.25
Cement, Portland	80–100	1.44
Cement, Rosendale	56	.89
Earth, dry, shaken	82–92	1.36
Earth, rammed	90–100	1.52
Earth, moist, shaken	75–100	1.31
Glass, average	186	2.98
Glass, common window	157	2.52
Granite	170	2.72
Gravel (see sand)		
Limestones and marbles	168	2.70
Lime, quick	53	.85
Marble (see limestone)		
Plaster of Paris	141.6	2.27
Porphyry	170.0	2.73
Quartz	165	2.65
Sand	90–106	2.65
Sandstone	151	2.41
Shales	162	2.60
Slate	175	2.80
Trap rock	187	3.00
Masonry.		
Common brickwork, cement mortar	130	2.10
Common brickwork, lime mortar	120	1.90
Granite or limestone rubble, dry	138	2.21
Granite or limestone rubble	154	2.45
Granite or limestone, well dressed	165	2.65
Mortar, hardened	103	1.65
Pressed brickwork	140	2.25
Sandstone rubble	145	2.32

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WOODS (DRY).

Name of Material	Weight per Foot. B. M.	Weight per Cu. Ft. Pounds.	Specific Gravity.
Ash	3.9	47.0	.752
Ash, American white	3.2	38.0	.610
Boxwood	5.0	60.0	.960
Cherry	3.5	42.0	.672
Chestnut	3.4	41.0	.660
Cork	1.3	15.6	.250
Elm	2.9	35.0	.560
Ebony	6.3	76.1	1.220
Hemlock	2.1	25.0	.400
Hickory	4.4	53.0	.850
Lignum vitæ	6.9	83.0	1.330
Mahogany, Spanish	4.4	53.0	.850
Mahogany, Honduras	2.9	35.0	.560
Maple	4.1	49.0	.790
Oak, live	4.9	59.3	.950
Oak, white	4.0	48.0	.770
Oak, red	3.3	40.0	.640
Pine, white	2.1	25.0	.400
Pine, yellow	2.8	34.3	.550
Pine, Southern	3.7	45.0	.720
Sycamore	3.1	37.0	.590
Spruce	2.1	25.0	.400
Walnut	3.2	38.0	.610

LIQUIDS.

Name of Liquid.	Weight per Cu. In. Pounds.	Specific Gravity.
Oil, linseed	.0340	.940
Oil, olive	.0331	.915
Oil, turpentine	.0314	.870
Alcohol, commercial	.0301	.833
Water, distilled, 39° F.	.0361	1.000
Water, sea	0372	1.030

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FORMULAS.

$$=\{+[-:(\sqrt{\times/+}):-]\}=$$

The term *formula*, as used in mathematics and in technical books, may be defined as *a rule in which symbols are used instead of words;* in fact, a formula may be regarded as a shorthand method of expressing a rule.

Most people having no knowledge of algebra regard formulas with distrust; they think that a person must be a good algebraic scholar in order to be able to use formulas. This idea, however, is erroneous. As a rule, no knowledge of any branch of mathematics except arithmetic is required to enable one to use a formula. Any formula can be expressed in words, and when so expressed it becomes a rule.

Formulas are much more convenient than rules; they show at a glance all the operations that are to be performed; they do not require to be read three or four times, as is the case with most rules, to enable one to understand their meaning; they take up much less space, both in the printed book and in one's note book, than rules; in short, whenever a rule can be expressed as a formula, the formula is to be preferred. In the following pages we purpose to show the reader how to use such formulas as he is likely to encounter in "pocket-books," or other works of like nature.

The signs used in formulas are the ordinary signs indicative of operations and the signs of aggregation. All these signs are used in arithmetic, but, to refresh the reader's memory, we will explain their nature and uses before proceeding further.

The signs indicative of operations are six in number, viz.: $+, -, \times, \div, |, \sqrt{}$.

The sign (+) indicates addition, and is called *plus;* when placed between two quantities, it indicates that the two quantities are to be added. Thus, in the expression $25+17$, the sign (+) shows that 17 is to be added to 25.

The sign (−) indicates subtraction, and is called *minus;* when placed between two quantities, it indicates that the

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quantity on the right is to be subtracted from that on the left. Thus, in the expression $25 - 17$, the sign $(-)$ shows that 17 is to be subtracted from 25.

The sign $(\times)$ indicates multiplication, and is read *times*, or *multiplied by;* when placed between two quantities, it indicates that the quantity on the left is to be multiplied by that on the right. Thus, in the expression 25×17, the sign $(\times)$ shows that 25 is to be multiplied by 17.

The sign $(\div)$ indicates division, and is read *divided by;* when placed between two quantities, it indicates that the quantity on the left is to be divided by that on the right. Thus, in the expression $25 \div 17$, the sign $(\div)$ shows that 25 is to be divided by 17.

Division is also indicated by placing a straight line between the two quantities. Thus, $25 \mid 17$, $25/17$, and $\frac{25}{17}$ all indicate that 25 is to be divided by 17. When both quantities are placed on the same horizontal line, the straight line indicates that the quantity on the left is to be divided by that on the right. When one quantity is below the other, the straight line between indicates that the quantity above the line is to be divided by the one below it.

The sign $(\surd)$ indicates that some root of the quantity to the right is to be taken; it is called the *radical* sign. To indicate what root is to be taken, a small figure, called the *index*, is placed within the sign, this being always omitted when the square root is to be indicated. Thus, $\surd 25$ indicates that the square root of 25 is to be taken; $\sqrt[3]{25}$ indicates that the cube root of 25 is to be taken, etc.

NOTE.—As the term "quantity" is a very convenient one to use, we will define it. In mathematics the word *quantity* is applied to anything that it is desired to subject to the ordinary operations of addition, subtraction, multiplication, etc., when we do not wish to be more specific and state exactly what the thing is. Thus, we can say "two or more numbers," or "two or more quantities." The word quantity is more general in its meaning than the word number.

The signs of aggregation are four in number, viz.: $\overline{\quad}$, $(\,)$, $[\,]$, and $\{\,\}$, respectively called the *vinculum*, the *parenthesis*, the *brackets*, and the *brace;* they are used when it is desired to indicate that all the quantities included by the

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are to be subjected to the same operation. Thus, if we desire to indicate that the sum of 5 and 8 is to be multiplied by 7, and we do not wish to actually add 5 and 8 before indicating the multiplication, we may employ any one of the four signs of aggregation as here shown: $\overline{5+8}\times 7$, $(5+8)\times 7$, $[5+8]\times 7$, $\{5+8\}\times 7$. The vinculum is placed above the quantities which are to be treated as one quantity and subjected to the same operations.

While any one of the four signs may be used as shown above, custom has restricted their use somewhat. The vinculum is rarely used except in connection with the radical sign. Thus, instead of writing $\sqrt[3]{(5+8)}$, $\sqrt[3]{[5+8]}$, or $\sqrt[3]{\{5+8\}}$ for the cube root of 5 plus 8, all of which would be correct, the vinculum is nearly always used, $\sqrt[3]{\overline{5+8}}$.

In cases where but one sign of aggregation is needed (except, of course, when a root is to be indicated), the parenthesis is always used. Hence, $(5+8)\times 7$ would be the usual way of expressing the product of 5 plus 8 and 7.

If two signs of aggregation are needed, the brackets and parenthesis are used, so as to avoid having a parenthesis within a parenthesis, the brackets being placed outside. For example, $[(20-5)\div 3]\times 9$ means that the difference between 20 and 5 is to be divided by 3, and this result multiplied by 9.

If three signs of aggregation are required, the brace, brackets, and parenthesis are used, the brace being placed outside, the brackets next, and the parenthesis inside. For example, $\{[(20-5)\div 3]\times 9-21\}\div 8$ means that the quotient obtained by dividing the difference between 20 and 5 by 3 is to be multiplied by 9; and that 21 is to be subtracted from the product thus obtained, and the result divided by 8.

Should it be necessary to use all four signs of aggregation, the brace would be put outside, the brackets next, the parenthesis next, and the vinculum inside. For example, $\{[(\overline{20-5}\div 3)\times 9-21]\div 8\}\times 12$. The reason for using the brace in this last instance will be explained, as it is not generally understood.

When several quantities are connected by the various signs indicating addition, subtraction, multiplication, and division, the operation indicated by the sign of multiplication

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must always be performed first. Thus, $2 + 3 \times 4$ equals 14, 3 being multiplied by 4 before adding to 2. Similarly, $10 \div 2 \times 5$ equals 1, since 2×5 equals 10, and $10 \div 10$ equals 1. Hence, in the above case, if the brace were omitted, the result would be $\frac{1}{4}$; whereas, by inserting the brace, the result is 36.

Following the sign of multiplication comes the sign of division in its order of importance. For example, $5 - 9 \div 3$ equals 2, 9 being divided by 3 before subtracting from 5. The signs of addition and subtraction are of equal value; that is, if several quantities are connected by plus and minus signs, the indicated operations may be performed in the order in which the quantities are placed.

There is one other sign used, which is neither a sign of aggregation nor a sign indicative of an operation to be performed; it is (=), and is called the sign of *equality;* it means that all on one side of it is exactly equal to all on the other side. For example, $2 = 2$, $5 - 3 = 2$, $5 \times (14 - 9) = 25$.

It is customary to omit the sign of multiplication between two or more quantities when they are to be multiplied together, or between a number and a letter representing a quantity, it being always understood that when two letters are adjacent with no sign between them, the quantities represented by these letters are to be multiplied.

The sign of multiplication, evidently, cannot be omitted between two or more numbers, as it would then be impossible to distinguish the numbers. A near approach to this, however, may be attained by placing a dot between the numbers that are to be multiplied together, and this is frequently done in works on mathematics when it is desired to economize space. In such cases it is usual to put the dot higher than the position occupied by the decimal point. Thus, 2·3 means the same as 2×3; 542·749·1,006 indicates that the numbers 542, 749, and 1,006 are to be multiplied together.

It is also customary to omit the sign of multiplication in expressions similar to the following: $a \times \sqrt{b + c}$, $3 \times (b + c)$, $(b + c) \times a$, etc., writing them $a\sqrt{b + c}$, $3(b + c)$, $(b + c)a$, etc. The sign is not omitted when several quantities are included by a vinculum, and it is desired to indicate that the quantities

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so included are to be multiplied by another quantity. For example, $3 \times \overline{b+c}$, $\overline{b+c} \times a$, $\sqrt{\overline{b+c}} \times a$, etc., are always written as here printed.

Before proceeding further, we will explain one other device that is used by formula makers, and which is apt to puzzle one who encounters it for the first time. It is the use of what mathematicians call *primes* and *subs.*, and what printers call *superior* and *inferior* characters. As a rule, formula makers designate quantities by the initial letters of the names of the quantities. For example, they represent volume by v, pressure by p, height by h, etc. This practice is to be commended, as the letter itself serves in many cases to identify the quantity that it represents. Some authors carry the practice a little further and represent all quantities of the same nature by the same letter throughout the book, always having the same letter represent the same thing. Now, this practice necessitates the use of the primes and subs. above mentioned when two quantities have the same name, but represent different things. Thus, consider the word *pressure* as applied to steam at different stages between the boiler and the condenser. First, there is *absolute* pressure, which is equal to the gauge pressure in pounds per square inch plus the pressure indicated by the barometer reading (usually assumed in practice to be 14.7 pounds per square inch, when a barometer is not at hand). If this be represented by p, how shall we represent the gauge pressure? Since the absolute pressure is always greater than the gauge pressure, suppose we decide to represent it by a capital letter, and the gauge pressure by a small (lower-case) letter. Doing so, P represents absolute pressure, and p gauge pressure. Further, there is usually a "drop" in pressure between the boiler and the engine, so that the initial pressure, or pressure at the beginning of the stroke, is less than the pressure at the boiler. How shall we represent the initial pressure? We may do this in one of three ways, and still retain the letter p or P to represent the word pressure: First, by the use of the prime mark; thus, p' or P' (read *p prime* and *p major prime*) may be considered to represent the initial gauge pressure or the initial absolute pressure.

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Second, by the use of sub. figures; thus, p_1 or P_1 (read *p sub. one* and *p major sub. one*). Third, by the use of sub. letters: thus, p_i or P_i (read *p sub. i* and *P major sub. i*). Likewise, p'' (read *p second*), p_2, or p_r might be used to represent the gauge pressure at release, etc. Sub. letters have the advantage of still further identifying the quantity represented; in many instances, however, it is not convenient to use them, in which case primes and subs. are used instead. The prime notation may be continued as follows: p''', p^{iv}, p^{v}, etc.; it is inadvisable to use superior figures, for example, p^1, p^2, p^3, p^4, etc., as they are liable to be mistaken for exponents.

The main thing to be remembered by the reader is that *when a formula is given in which the same letters occur several times, all like letters having the same primes or subs. represent the same quantities, while those that differ in any respect represent different quantities.* Thus, in the formula

$$t = \frac{w_1 s_1 t_1 + w_2 s_2 t_2 + w_3 s_3 t_3}{w_1 s_1 + w_2 s_2 + w_3 s_3},$$

w_1, w_2, and w_3 represent the weights of three different bodies; s_1, s_2, and s_3 their specific heats; and t_1, t_2, and t_3 their temperatures; while t represents the final temperature, after the bodies have been mixed together.

It is very easy to apply the above formula when the values of the quantities represented by the different letters are known. All that is required is to substitute the numerical values of the letters, and then perform the indicated operations. Thus, suppose that the values of w_1, s_1, and t_1 are, respectively, 2 pounds, .0951, and 80°; of w_2, s_2, and t_2, 7.8 pounds, 1, and 80°, and of w_3, s_3, and t_3, 3¼ pounds, .1138, and 780°; then, the final temperature t is, substituting these values for their respective letters in the formula,

$$t = \frac{2 \times .0951 \times 80 + 7.8 \times 1 \times 80 + 3\frac{1}{4} \times .1138 \times 780}{2 \times .0951 + 7.8 \times 1 + 3\frac{1}{4} \times .1138} =$$

$$\frac{15.216 + 624 + 288.483}{.1902 + 7.8 + .36985} = \frac{927.699}{8.36005} = 110.97°.$$

In substituting the numerical values, the signs of multiplication are, of course, written in their proper places; all the multiplications are performed before adding, according to the rule previously given.

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The reader should now be able to apply any formula involving only algebraic expressions that he may meet with, not requiring the use of logarithms for their solution. We will, however, call his attention to one or two other facts which he may have forgotten.

Expressions similar to $\frac{160}{\frac{660}{25}}$ sometimes occur, the heavy line indicating that 160 is to be divided by the quotient obtained by dividing 660 by 25. If both lines were light it would be impossible to tell whether 160 was to be divided by $\frac{660}{25}$, or whether $\frac{160}{660}$ was to be divided by 25. If this latter result were desired, the expression would be written $\frac{\frac{160}{660}}{25}$. In every case the heavy line indicates that all above it is to be divided by all below it.

In an expression like the following, $\frac{160}{7+\frac{660}{25}}$, the heavy line is not necessary, since it is impossible to mistake the operation that is required to be performed. But, since $7+\frac{660}{25} = \frac{175+660}{25}$, if we substitute $\frac{175+660}{25}$ for $7+\frac{660}{25}$, the heavy line becomes necessary in order to make the resulting expression clear. Thus,

$$\frac{160}{7+\frac{660}{25}} = \frac{160}{\frac{175+660}{25}} = \frac{160}{\frac{835}{25}}.$$

Fractional exponents are sometimes used instead of the radical sign. That is, instead of indicating the square, cube, fourth root, etc. of some quantity, as 37 by $\sqrt{37}$, $\sqrt[3]{37}$, $\sqrt[4]{37}$, etc. these roots are indicated by $37^{\frac{1}{2}}$, $37^{\frac{1}{3}}$, $37^{\frac{1}{4}}$, etc. Should the numerator of the fractional exponent be some quantity other than 1, this quantity, whatever it may be, indicates that the quantity affected by the exponent is to be raised to the power indicated by the numerator; the denominator is

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always the index of the root. Hence, instead of expressing the cube root of the square of 37 as $\sqrt[3]{37^2}$, it may be expressed $37^{\frac{2}{3}}$, the denominator being the index of the root; in other words, $\sqrt[3]{37^2} = 37^{\frac{2}{3}}$. Likewise, $\sqrt[5]{(1+a^2b)^3}$ may also be written $(1+a^2b)^{\frac{3}{5}}$, a much simpler expression.

We will now give several examples showing how to apply some of the more difficult formulas that the reader may encounter.

The area of any segment of a circle that is less than (or equal to) a semicircle is expressed by the formula.

$$A = \frac{\pi r^2 E}{360} - \frac{c}{2}(r-h),$$

in which A = area of segment;
π = 3.1416;
r = radius;
E = angle obtained by drawing lines from the center to the extremities of arc of segment;
c = chord of segment;
h = height of segment.

EXAMPLE.—What is the area of a segment whose chord is 10 in. long, angle subtended by chord is 83.46°, radius is 7.5 in., and height of segment is 1.91 in.?

SOLUTION.—Applying the formula just given,

$$A = \frac{\pi r^2 E}{360} - \frac{c}{2}(r-h) = \frac{3.1416 \times 7.5^2 \times 83.46}{360} - \frac{10}{2}(7.5-1.91)$$
$$= 40.968 - 27.95 = 13.018 \text{ sq. in., nearly.}$$

The area of any triangle may be found by means of the following formula, in which A = the area, and a, b, and c represent the lengths of the sides:

$$A = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2+b^2-c^2}{2b}\right)^2}.$$

EXAMPLE.—What is the area of a triangle whose sides are 21 ft., 46 ft., and 50 ft. long?

SOLUTION.—In order to apply the formula, suppose we let a represent the side that is 21 ft. long; b, the side that is 50 ft. long; and c, the side that is 46 ft. long. Then, substituting in the formula,

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$$A = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2} = \frac{50}{2}\sqrt{21^2 - \left(\frac{21^2 + 50^2 - 46^2}{2 \times 50}\right)^2}$$

$$= \frac{50}{2}\sqrt{441 - \left(\frac{441 + 2{,}500 - 2{,}116}{100}\right)^2} = 25\sqrt{441 - \left(\frac{825}{100}\right)^2}$$

$$= 25\sqrt{441 - 8.25^2} = 25\sqrt{441 - 68.0625} = 25\sqrt{372.9375}$$

$$= 25 \times 19.312 = 482.8 \text{ sq. ft., nearly.}$$

The above operations have been extended much further than was necessary; this was done in order to show the reader every step of the process.

The Rankine-Gordon formula for determining the least load in pounds that will cause a long column to break is

$$P = \frac{SA}{1 + q\frac{l^2}{G^2}},$$

in which P = load (pressure) in lb.; S = ultimate strength (in lb. per sq. in.) of material composing column; A = area of cross-section of column in sq. in.; q = a factor (multiplier) whose value depends on the shape of the ends of the column and on the material composing the column; l = length of the column in in.; G = least radius of gyration of cross-section of column.

The values of S, q, and G^2 are all given in tables to be found in books on strength of materials.

EXAMPLE.—What is the least load that will break a hollow wrought-iron column whose outside diameter is 14 in., inside diameter 11 in., length 20 ft., and whose ends are flat?

SOLUTION.—For steel, $S = 150{,}000$, and $q = \frac{1}{25{,}000}$ for flat-ended steel columns; A, the area of the cross-section, $= .7854(d_1^2 - d_2^2)$, d_1 and d_2 being the outside and inside diameters, respectively; $l = 20 \times 12 = 240$ in.; and $G^2 = \frac{d_1^2 + d_2^2}{16}$. Substituting these values in the formula,

$$P = \frac{SA}{1 + q\frac{l^2}{G^2}} = \frac{150{,}000 \times .7854(14^2 - 11^2)}{1 + \frac{1}{25{,}000} \times \frac{240^2}{\frac{14^2 + 11^2}{16}}} =$$

$$\frac{150{,}000 \times 58.905}{1 + .1163} = \frac{8{,}835.750}{1.1163} = 7{,}915{,}211 \text{ lb.}$$

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MENSURATION.

In the following formulas, the letters have the meanings here given, unless otherwise stated.

D = larger diameter;
d = smaller diameter;
R = radius corresponding to D;
r = radius corresponding to d;
p = perimeter or circumference;
C = area of convex surface = area of flat surface which can be rolled into the shape shown;
S = area of entire surface = C + area of the end or ends;
A = area of plane figure;
π = 3.1416, nearly = ratio of any circumference to its diameter;
V = volume of solid.

The other letters used will be found on the cuts.

CIRCLE.

$$p = \pi d = 3.1416\, d.$$

$$p = 2\pi r = 6.2832\, r.$$

$$p = 2\sqrt{\pi A} = 3.5449\sqrt{A}.$$

$$p = \frac{2A}{r} = \frac{4A}{d}.$$

$$d = \frac{p}{\pi} = \frac{p}{3.1416} = .3183\, p.$$

$$d = 2\sqrt{\frac{A}{\pi}} = 1.1284\sqrt{A}.$$

$$r = \frac{p}{2\pi} = \frac{p}{6.2832} = .1592\, p.$$

$$r = \sqrt{\frac{A}{\pi}} = .5642\sqrt{A}.$$

$$A = \frac{\pi d^2}{4} = .7854\, d^2.$$

$$A = \pi r^2 = 3.1416\, r^2.$$

$$A = \frac{pr}{2} = \frac{pd}{4}.$$

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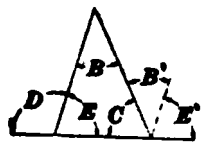
TRIANGLES.



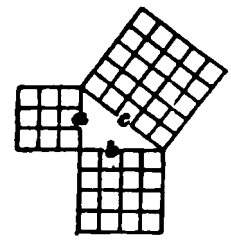
$D = B + C.$ $\quad E + B + C = 180°.$

$B = D - C.$ $\quad E' + B + C = 180°.$

$E' = E.$ $\quad B' = B.$

The above letters refer to angles.

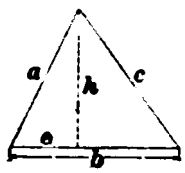
For a right-angled triangle, c being the hypotenuse,



$$c = \sqrt{a^2 + b^2}.$$

$$a = \sqrt{c^2 - b^2}.$$

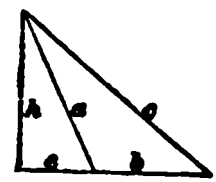
$$b = \sqrt{c^2 - a^2}.$$



c = length of side opposite an acute angle of an oblique-angled triangle.

$$c = \sqrt{a^2 + b^2 - 2be}.$$

$$h = \sqrt{a^2 - e^2}.$$

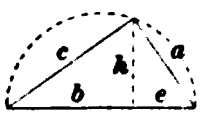


c = length of side opposite an obtuse angle of an oblique-angled triangle.

$$c = \sqrt{a^2 + b^2 + 2be}.$$

$$h = \sqrt{a^2 - e^2}.$$

For a triangle inscribed in a semicircle; i. e., any right-angled triangle,

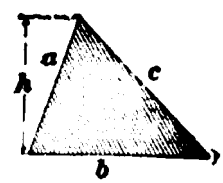


$$c : b :: a : h.$$

$$h = \frac{ab}{c} = \frac{ce}{a}.$$

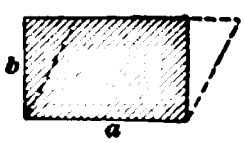
$$a : b + e = e : a = h : c.$$

For any triangle,



$$A = \frac{bh}{2} = \tfrac{1}{2} b\,h.$$

$$A = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2}.$$



RECTANGLE AND PARALLELOGRAM.

$$A = a\,b.$$

$$A = b\sqrt{c^2 - b^2}.$$

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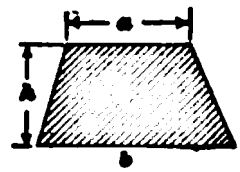
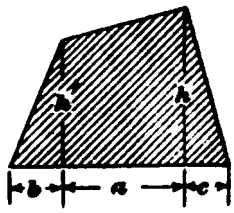
TRAPEZOID.

$A = \frac{1}{2}h(a + b)$.



TRAPEZIUM.

Divide into two triangles and a trapezoid.



$$A = \tfrac{1}{2} b\, h' + \tfrac{1}{2} a(h' + h) + \tfrac{1}{2} c\, h;$$

or, $A = \frac{1}{2}[b\, h' + c\, h + a(h' + h)]$.

Or, divide into two triangles by drawing a diagonal. Consider the diagonal as the base of both triangles, call its length l; call the altitudes of the triangles h_1 and h_2; then

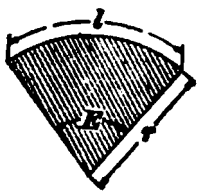
$$A = \tfrac{1}{2}\, l(h_1 + h_2).$$

ELLIPSE.

$$p^* = \pi \sqrt{\frac{D^2 + d^2}{2} - \frac{(D - d)^2}{8.8}}.$$

$$A = \frac{\pi}{4} D\, d = .7854\ D\, d.$$

SECTOR.



$$A = \tfrac{1}{2}\, l\, r.$$

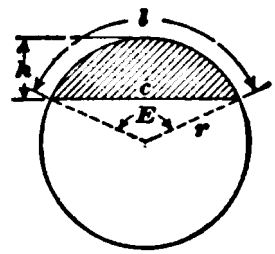
$$A = \frac{\pi\, r^2\, E}{360} = .008727\ r^2\, E.$$

l = length of arc.

SEGMENT.

$$A = \tfrac{1}{2}[l\, r - c(r - h)].$$

$$A = \frac{\pi\, r^2\, E}{360} - \frac{c}{2}(r - h).$$



$$l = \frac{\pi\, r\, E}{180} = .0175\ r\, E.$$

$$E = \frac{180\, l}{\pi\, r} = 57.2956\, \frac{l}{r}$$

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* The perimeter of an ellipse cannot be exactly determined without a very elaborate calculation, and this formula is merely an approximation giving fairly close results.

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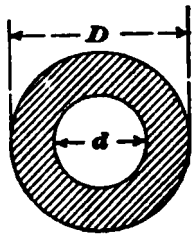
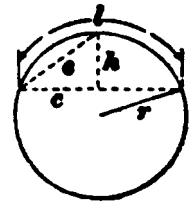


RING.

$$A = \frac{\pi}{4}(D^2 - d^2).$$

CHORD.

c = length of chord.

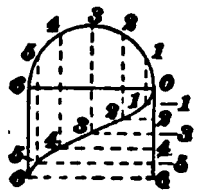


$$r = \frac{c^2 + 4h^2}{8h} = \frac{e^2}{2h}.$$

$$c = 2\sqrt{2hr - h^2}.$$

$$l = \frac{8e - c}{3}, \text{ approximately.}$$

HELIX.

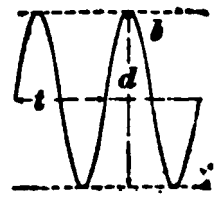


To construct a helix.

l = length of helix;

n = number of turns;

t = pitch.

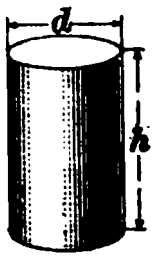


$$t = \sqrt{\frac{l^2}{n^2} - \pi^2 d^2}.$$

$$l = n\sqrt{\pi^2 d^2 + t^2}.$$

$$n = \frac{l}{\sqrt{\pi^2 a^2 + t^2}}.$$

CYLINDER.



$$C = \pi d h.$$

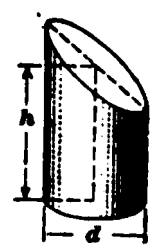
$$S = 2\pi r h + 2\pi r^2$$

$$= \pi d h + \frac{\pi}{2} d^2.$$

$$V = \pi r^2 h = \frac{\pi}{4} d^2 h.$$

$$V = \frac{p^2 h}{4\pi} = .0796\, p^2 h.$$

FRUSTUM OF CYLINDER.



$h = \frac{1}{2}$ sum of greatest and least heights.

$$C = p h = \pi d h.$$

$$S = \pi d h + \frac{\pi}{4} d^2 + \text{area of elliptical top.}$$

$$V = A h = \frac{\pi}{4} d^2 h.$$

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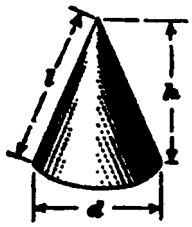


CONE.

$$C = \tfrac{1}{2}\pi d\, l = \pi r\, l.$$

$$S = \pi r\, l + \pi r^2 = \pi r \sqrt{r^2 + h^2} + \pi r^2.$$

$$V = \frac{\pi d^2}{4} \times \frac{h}{3} = \frac{.7854\, d^2 h}{3} = \frac{p^2 h}{12\pi}.$$

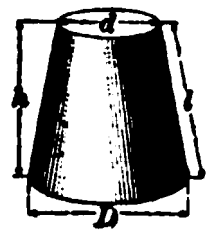
FRUSTUM OF CONE.

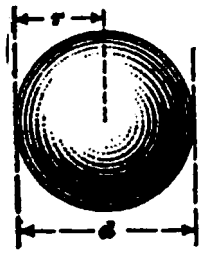
$$C = \tfrac{1}{2}\, l\,(P + p) = \frac{\pi}{2} l\,(D + d).$$

$$S = \frac{\pi}{2}\,[l\,(D + d) + \tfrac{1}{2}\,(D^2 + d^2)].$$

$$V = \frac{\pi}{4}\,(D^2 + D\,d + d^2) \times \tfrac{1}{3}\,h$$

$$= .2618\, h\,(D^2 + D\,d + d^2).$$





SPHERE.

$$S = \pi\, d^2 = 4\,\pi\, r^2 = 12.5664\, r^2.$$

$$V = \tfrac{1}{6}\,\pi\, d^3 = \tfrac{4}{3}\,\pi\, r^3 = .5236\, d^3 = 4.1888\, r^3.$$

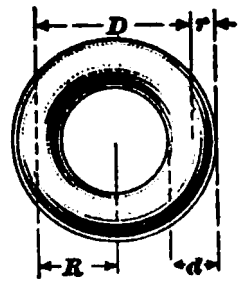
CIRCULAR RING.

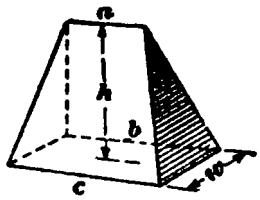
D = mean diameter;

R = mean radius.

$$S = 4\,\pi^2\, R\, r = 9.8696\, D\, d.$$

$$V = 2\,\pi^2\, R\, r^2 = 2.4674\, D\, d^2.$$





WEDGE.

$$V = \tfrac{1}{6}\, w\, h\,(a + b + c).$$

PRISMOID.

A prismoid is a solid having two parallel plane ends, the edges of which are connected by plane triangular or quadrilateral surfaces.

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A = area one end;
a = area of other end;
m = area of section midway between ends;
l = perpendicular distance between ends.

$$V = \tfrac{1}{6} l(A + a + 4m).$$

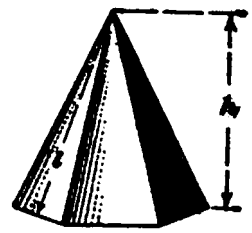
The area m is not in general a mean between the areas of the two ends, but its sides are means between the corresponding lengths of the ends.

Approximately, $V = \dfrac{A + a}{2} l.$

REGULAR PYRAMID.

P = perimeter of base;
A = area of base.

$$C = \tfrac{1}{2} P l.$$
$$S = \tfrac{1}{2} P l + A.$$
$$V = \frac{A h}{3}.$$

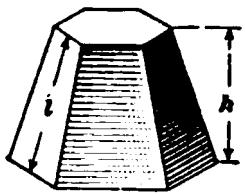


To obtain area of base, divide it into triangles, and find their sum.

The formula for V applies to any pyramid whose base is A and altitude h.

FRUSTUM OF REGULAR PYRAMID.

a = area of upper base;
A = area of lower base;
p = perimeter of upper base;
P = perimeter of lower base.



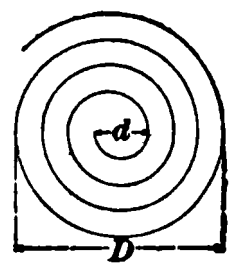
$$C = \tfrac{1}{2} l(P + p).$$
$$S = \tfrac{1}{2} l(P + p) + A + a.$$
$$V = \tfrac{1}{3} h\left(A + a + \sqrt{A\,a}\right).$$

The formula for V applies to the frustum of any pyramid.

LENGTH OF SPIRAL.

$$l = \pi n\left(\frac{D + d}{2}\right).$$
$$= \frac{\pi}{t}(R^2 - r^2.$$

n = number of coil;
l = length of spiral;
t = pitch.



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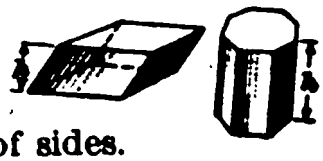
PRISM OR PARALLELOPIPED.

$C = P\,h.$

$S = P\,h + 2\,A.$

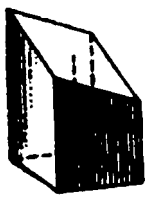
$V = A\,h.$



For prisms with regular polygon as bases, P = length of one side $\times$ number of sides.

To obtain area of base, if it is a polygon, divide it into triangles, and find sum of partial areas.

FRUSTUM OF PRISM.

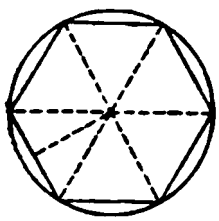


If a section perpendicular to the edges is a triangle, square, parallelogram, or *regular* polygon,

$$V = \frac{\text{sum of lengths of edges}}{\text{number of edges}} \times \text{area of right section.}$$

REGULAR POLYGONS.

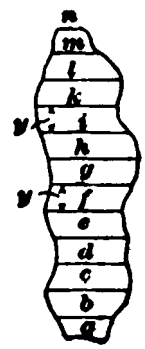
Divide the polygon into equal triangles and find the sum of the partial areas. Otherwise, square the length of one side and multiply by proper number from the following table:



Name.	*No. Sides.*	*Multiplier*
Triangle	3	.433
Square	4	1.000
Pentagon	5	1.720
Hexagon	6	2.598
Heptagon	7	3.634
Octagon	8	4.828
Nonagon	9	6.182
Decagon	10	7.694

IRREGULAR AREAS.

Divide the area into trapezoids, triangles, parts of circles, etc., and find the sum of the partial areas.



If the figure is very irregular, the approximate area may be found as follows: Divide the figure into parts by equidistant parallel lines b, c, d, etc. The lengths of these lines being measured, then, calling a the first and n the last length, and y the width of strips,

$$\text{Area} = y\left(\frac{a+n}{2} + b + c + \text{etc.} + m\right).$$

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CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64 TO 100.

Diam.	Circum.	Area.	Diam.	Circum.	Area.
1/64	.0491	.0002	4 1/8	13.7445	15.0330
1/32	.0982	.0008	4 1/4	14.1372	15.9043
3/64	.1963	.0031	4 3/8	14.5299	16.8002
1/16	.3927	.0123	4 1/2	14.9226	17.7206
5/64	.5890	.0276	4 5/8	15.3153	18.6555
3/32	.7854	.0491	5	15.7080	19.6350
7/64	.9817	.0767	5 1/8	16.1007	20.6290
1/8	1.1781	.1104	5 1/4	16.4934	21.6476
9/64	1.3744	.1503	5 3/8	16.8861	22.6907
5/32	1.5708	.1963	5 1/2	17.2788	23.7583
11/64	1.7671	.2485	5 5/8	17.6715	24.8505
3/16	1.9635	.3068	5 3/4	18.0642	25.9673
13/64	2.1598	.3712	5 7/8	18.4569	27.1086
7/32	2.3562	.4418	6	18.8496	28.2744
15/64	2.5525	.5185	6 1/8	19.2423	29.4648
1/4	2.7489	.6013	6 1/4	19.6350	30.6797
17/64	2.9452	.6903	6 3/8	20.0277	31.9191
1	3.1416	.7854	6 1/2	20.4204	33.1831
1 1/8	3.5343	.9940	6 5/8	20.8131	34.4717
1 1/4	3.9270	1.2272	6 3/4	21.2058	35.7848
1 3/8	4.3197	1.4849	6 7/8	21.5985	37.1224
1 1/2	4.7124	1.7671	7	21.9912	38.4846
1 5/8	5.1051	2.0739	7 1/8	22.3839	39.8713
1 3/4	5.4978	2.4053	7 1/4	22.7766	41.2826
1 7/8	5.8905	2.7612	7 3/8	23.1693	42.7184
2	6.2832	3.1416	7 1/2	23.5620	44.1787
2 1/8	6.6759	3.5466	7 5/8	23.9547	45.6636
2 1/4	7.0686	3.9761	7 3/4	24.3474	47.1731
2 3/8	7.4613	4.4301	7 7/8	24.7401	48.7071
2 1/2	7.8540	4.9087	8	25.1328	50.2656
2 5/8	8.2467	5.4119	8 1/8	25.5255	51.8487
2 3/4	8.6394	5.9396	8 1/4	25.9182	53.4563
2 7/8	9.0321	6.4918	8 3/8	26.3109	55.0884
3	9.4248	7.0686	8 1/2	26.7036	56.7451
3 1/8	9.8175	7.6699	8 5/8	27.0963	58.4264
3 1/4	10.2102	8.2958	8 3/4	27.4890	60.1322
3 3/8	10.6029	8.9462	8 7/8	27.8817	61.8625
3 1/2	10.9956	9.6211	9	28.2744	63.6174
3 5/8	11.3883	10.3206	9 1/8	28.6671	65.3968
3 3/4	11.7810	11.0447	9 1/4	29.0598	67.2008
3 7/8	12.1737	11.7933	9 3/8	29.4525	69.0293
4	12.5664	12.5664	9 1/2	29.8452	70.8823
4 1/8	12.9591	13.3641	9 5/8	30.2379	72.7599
4 1/4	13.3518	14.1863	9 3/4	30.6306	74.6621

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
9⅞	31.0233	76.589	15⅛	49.0875	191.748
10	31.4160	78.540	15¼	49.4802	194.828
10⅛	31.8087	80.516	15⅜	49.8729	197.933
10¼	32.2014	82.516	16	50.2656	201.062
10⅜	32.5941	84.541	16⅛	50.6583	204.216
10½	32.9868	86.590	16¼	51.0510	207.395
10⅝	33.3795	88.664	16⅜	51.4437	210.598
10¾	33.7722	90.763	16½	51.8364	213.825
10⅞	34.1649	92.886	16⅝	52.2291	217.077
11	34.5576	95.033	16¾	52.6218	220.354
11⅛	34.9503	97.205	16⅞	53.0145	223.655
11¼	35.3430	99.402	17	53.4072	226.981
11⅜	35.7357	101.623	17⅛	53.7999	230.331
11½	36.1284	103.869	17¼	54.1926	233.706
11⅝	36.5211	106.139	17⅜	54.5853	237.105
11¾	36.9138	108.434	17½	54.9780	240.529
11⅞	37.3065	110.754	17⅝	55.3707	243.977
12	37.6992	113.098	17¾	55.7634	247.450
12⅛	38.0919	115.466	17⅞	56.1561	250.948
12¼	38.4846	117.859	18	56.5488	254.470
12⅜	38.8773	120.277	18⅛	56.9415	258.016
12½	39.2700	122.719	18¼	57.3342	261.587
12⅝	39.6627	125.185	18⅜	57.7269	265.183
12¾	40.0554	127.677	18½	58.1196	268.803
12⅞	40.4481	130.192	18⅝	58.5123	272.448
13	40.8408	132.733	18¾	58.9050	276.117
13⅛	41.2335	135.297	18⅞	59.2977	279.811
13¼	41.6262	137.887	19	59.6904	283.529
13⅜	42.0189	140.501	19⅛	60.0831	287.272
13½	42.4116	143.139	19¼	60.4758	291.040
13⅝	42.8043	145.802	19⅜	60.8685	294.832
13¾	43.1970	148.490	19½	61.2612	298.648
13⅞	43.5897	151.202	19⅝	61.6539	302.489
14	43.9824	153.938	19¾	62.0466	306.355
14⅛	44.3751	156.700	19⅞	62.4393	310.245
14¼	44.7678	159.485	20	62.8320	314.160
14⅜	45.1605	162.296	20⅛	63.2247	318.099
14½	45.5532	165.130	20¼	63.6174	322.063
14⅝	45.9459	167.990	20⅜	64.0101	326.051
14¾	46.3386	170.874	20½	64.4028	330.064
14⅞	46.7313	173.782	20⅝	64.7955	334.102
15	47.1240	176.715	20¾	65.1882	338.164
15⅛	47.5167	179.673	20⅞	65.5809	342.250
15¼	47.9094	182.655	21	65.9736	346.361
15⅜	48.3021	185.661	21⅛	66.3663	350.497
15½	48.6948	188.692	21¼	66.7590	354.657

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
21⅛	67.1517	358.842	27⅛	85.2159	577.870
21¼	67.5444	363.051	27¼	85.6086	583.209
21⅜	67.9371	367.285	27⅜	86.0013	588.571
21½	68.3298	371.543	27½	86.3940	593.959
21⅞	68.7225	375.826	27⅝	86.7867	599.371
22	69.1152	380.134	27¾	87.1794	604.807
22⅛	69.5079	384.466	27⅞	87.5721	610.268
22¼	69.9006	388.822	28	87.9648	615.754
22⅜	70.2933	393.203	28⅛	88.3575	621.264
22½	70.6860	397.609	28¼	88.7502	626.798
22⅝	71.0787	402.038	28⅜	89.1429	632.357
22¾	71.4714	406.494	28½	89.5356	637.941
22⅞	71.8641	410.973	28⅝	89.9283	643.549
23	72.2568	415.477	28¾	90.3210	649.182
23⅛	72.6495	420.004	28⅞	90.7137	654.840
23¼	73.0422	424.558	29	91.1064	660.521
23⅜	73.4349	429.135	29⅛	91.4991	666.228
23½	73.8276	433.737	29¼	91.8918	671.959
23⅝	74.2203	438.364	29⅜	92.2845	677.714
23¾	74.6130	443.015	29½	92.6772	683.494
23⅞	75.0057	447.690	29⅝	93.0699	689.299
24	75.3984	452.390	29¾	93.4626	695.128
24⅛	75.7911	457.115	29⅞	93.8553	700.982
24¼	76.1838	461.864	30	94.2480	706.860
24⅜	76.5765	466.638	30⅛	94.6407	712.763
24½	76.9692	471.436	30¼	95.0334	718.690
24⅝	77.3619	476.259	30⅜	95.4261	724.642
24¾	77.7546	481.107	30½	95.8188	730.618
24⅞	78.1473	485.979	30⅝	96.2115	736.619
25	78.5400	490.875	30¾	96.6042	742.645
25⅛	78.9327	495.796	30⅞	96.9969	748.695
25¼	79.3254	500.742	31	97.3896	754.769
25⅜	79.7181	505.712	31⅛	97.7823	760.869
25½	80.1108	510.706	31¼	98.1750	766.992
25⅝	80.5035	515.726	31⅜	98.5677	773.140
25¾	80.8962	520.769	31½	98.9604	779.313
25⅞	81.2889	525.838	31⅝	99.3531	785.510
26	81.6816	530.930	31¾	99.7458	791.732
26⅛	82.0743	536.048	31⅞	100.1385	797.979
26¼	82.4670	541.190	32	100.5312	804.250
26⅜	82.8597	546.356	32⅛	100.9239	810.545
26½	83.2524	551.547	32¼	101.3166	816.865
26⅝	83.6451	556.763	32⅜	101.7093	823.210
26¾	84.0378	562.003	32½	102.1020	829.579
26⅞	84.4305	567.267	32⅝	102.4947	835.972
27	84.8232	572.557	32¾	102.8874	842.391

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
32⅛	103.280	848.833	38⅛	121.344	1,171.731
33	103.673	855.301	38¼	121.737	1,179.327
33⅛	104.065	861.792	38⅜	122.130	1,186.948
33¼	104.458	868.309	39	122.522	1,194.593
33⅜	104.851	874.850	39⅛	122.915	1,202.263
33½	105.244	881.415	39¼	123.308	1,209.958
33⅝	105.636	888.005	39⅜	123.700	1,217.677
33¾	106.029	894.620	39½	124.093	1,225.420
33⅞	106.422	901.259	39⅝	124.486	1,233.188
34	106.814	907.922	39¾	124.879	1,240.981
34⅛	107.207	914.611	39⅞	125.271	1,248.798
34¼	107.600	921.323	40	125.664	1,256.640
34⅜	107.992	928.061	40⅛	126.057	1,264.510
34½	108.385	934.822	40¼	126.449	1,272.400
34⅝	108.778	941.609	40⅜	126.842	1,280.310
34¾	109.171	948.420	40½	127.235	1,288.250
34⅞	109.563	955.255	40⅝	127.627	1,296.220
35	109.956	962.115	40¾	128.020	1,304.210
35⅛	110.349	969.000	40⅞	128.413	1,312.220
35¼	110.741	975.909	41	128.806	1,320.260
35⅜	111.134	982.842	41⅛	129.198	1,328.320
35½	111.527	989.800	41¼	129.591	1,336.410
35⅝	111.919	996.783	41⅜	129.984	1,344.520
35¾	112.312	1,003.790	41½	130.376	1,352.660
35⅞	112.705	1,010.822	41⅝	130.769	1,360.820
36	113.098	1,017.878	41¾	131.162	1,369.000
36⅛	113.490	1,024.960	41⅞	131.554	1,377.210
36¼	113.883	1,032.065	42	131.947	1,385.450
36⅜	114.276	1,039.195	42⅛	132.340	1,393.700
36½	114.668	1,046.349	42¼	132.733	1,401.990
36⅝	115.061	1,053.528	42⅜	133.125	1,410.300
36¾	115.454	1,060.732	42½	133.518	1,418.630
36⅞	115.846	1,067.960	42⅝	133.911	1,426.990
37	116.239	1,075.213	42¾	134.303	1,435.370
37⅛	116.632	1,082.490	42⅞	134.696	1,443.770
37¼	117.025	1,089.792	43	135.089	1,452.200
37⅜	117.417	1,097.118	43⅛	135.481	1,460.660
37½	117.810	1,104.469	43¼	135.874	1,469.140
37⅝	118.203	1,111.844	43⅜	136.267	1,477.640
37¾	118.595	1,119.244	43½	136.660	1,486.170
37⅞	118.988	1,126.669	43⅝	137.052	1,494.730
38	119.381	1,134.118	43¾	137.445	1,503.300
38⅛	119.773	1,141.591	43⅞	137.838	1,511.910
38¼	120.166	1,149.089	44	138.230	1,520.530
38⅜	120.559	1,156.612	44⅛	138.623	1,529.190
38½	120.952	1,164.159	44¼	139.016	1,537.860

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
44⅛	139.408	1,546.56	50⅛	157.473	1,973.33
44¼	139.801	1,555.29	50¼	157.865	1,983.18
44⅜	140.194	1,564.04	50⅜	158.258	1,993.06
44½	140.587	1,572.81	50½	158.651	2,002.97
44⅝	140.979	1,581.61	50⅝	159.043	2,012.89
45	141.372	1,590.43	50¾	159.436	2,022.85
45⅛	141.765	1,599.28	50⅞	159.829	2,032.82
45¼	142.157	1,608.16	51	160.222	2,042.83
45⅜	142.550	1,617.05	51⅛	160.614	2,052.85
45½	142.943	1,625.97	51¼	161.007	2,062.90
45⅝	143.335	1,634.92	51⅜	161.400	2,072.98
45¾	143.728	1,643.89	51½	161.792	2,083.08
45⅞	144.121	1,652.89	51⅝	162.185	2,093.20
46	144.514	1,661.91	51¾	162.578	2,103.35
46⅛	144.906	1,670.95	51⅞	162.970	2,113.52
46¼	145.299	1,680.02	52	163.363	2,123.72
46⅜	145.692	1,689.11	52⅛	163.756	2,133.94
46½	146.084	1,698.23	52¼	164.149	2,144.19
46⅝	146.477	1,707.37	52⅜	164.541	2,154.46
46¾	146.870	1,716.54	52½	164.934	2,164.76
46⅞	147.262	1,725.73	52⅝	165.327	2,175.08
47	147.655	1,734.95	52¾	165.719	2,185.42
47⅛	148.048	1,744.19	52⅞	166.112	2,195.79
47¼	148.441	1,753.45	53	166.505	2,206.19
47⅜	148.833	1,762.74	53⅛	166.897	2,216.61
47½	149.226	1,772.06	53¼	167.290	2,227.05
47⅝	149.619	1,781.40	53⅜	167.683	2,237.52
47¾	150.011	1,790.76	53½	168.076	2,248.01
47⅞	150.404	1,800.15	53⅝	168.468	2,258.53
48	150.797	1,809.56	53¾	168.861	2,269.07
48⅛	151.189	1,819.00	53⅞	169.254	2,279.64
48¼	151.582	1,828.46	54	169.646	2,290.23
48⅜	151.975	1,837.95	54⅛	170.039	2,300.84
48½	152.368	1,847.46	54¼	170.432	2,311.48
48⅝	152.760	1,856.99	54⅜	170.824	2,322.15
48¾	153.153	1,866.55	54½	171.217	2,332.83
48⅞	153.546	1,876.14	54⅝	171.610	2,343.55
49	153.938	1,885.75	54¾	172.003	2,354.29
49⅛	154.331	1,895.38	54⅞	172.395	2,365.05
49¼	154.724	1,905.04	55	172.788	2,375.83
49⅜	155.116	1,914.72	55⅛	173.181	2,386.65
49½	155.509	1,924.43	55¼	173.573	2,397.48
49⅝	155.902	1,934.16	55⅜	173.966	2,408.34
49¾	156.295	1,943.91	55½	174.359	2,419.23
49⅞	156.687	1,953.69	55⅝	174.751	2,430.14
50	157.080	1,963.50	55¾	175.144	2,441.07

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
55 7/8	175.537	2,452.03	61 1/8	193.601	2,982.67
56	175.930	2,463.01	61 2/8	193.994	2,994.78
56 1/8	176.322	2,474.02	61 3/8	194.386	3,006.92
56 2/8	176.715	2,485.05	62	194.779	3,019.08
56 3/8	177.108	2,496.11	62 1/8	195.172	3,031.26
56 4/8	177.500	2,507.19	62 2/8	195.565	3,043.47
56 5/8	177.893	2,518.30	62 3/8	195.957	3,055.71
56 6/8	178.286	2,529.43	62 4/8	196.350	3,067.97
56 7/8	178.678	2,540.58	62 5/8	196.743	3,080.25
57	179.071	2,551.76	62 6/8	197.135	3,092.56
57 1/8	179.464	2,562.97	62 7/8	197.528	3,104.89
57 2/8	179.857	2,574.20	63	197.921	3,117.25
57 3/8	180.249	2,585.45	63 1/8	198.313	3,129.64
57 4/8	180.642	2,596.73	63 2/8	198.706	3,142.04
57 5/8	181.035	2,608.03	63 3/8	199.099	3,154.47
57 6/8	181.427	2,619.36	63 4/8	199.492	3,166.93
57 7/8	181.820	2,630.71	63 5/8	199.884	3,179.41
58	182.213	2,642.09	63 6/8	200.277	3,191.91
58 1/8	182.605	2,653.49	63 7/8	200.670	3,204.44
58 2/8	182.998	2,664.91	64	201.062	3,217.00
58 3/8	183.391	2,676.36	64 1/8	201.455	3,229.58
58 4/8	183.784	2,687.84	64 2/8	201.848	3,242.18
58 5/8	184.176	2,699.33	64 3/8	202.240	3,254.81
58 6/8	184.569	2,710.86	64 4/8	202.633	3,267.46
58 7/8	184.962	2,722.41	64 5/8	203.026	3,280.14
59	185.354	2,733.98	64 6/8	203.419	3,292.84
59 1/8	185.747	2,745.57	64 7/8	203.811	3,305.56
59 2/8	186.140	2,757.20	65	204.204	3,318.31
59 3/8	186.532	2,768.84	65 1/8	204.597	3,331.09
59 4/8	186.925	2,780.51	65 2/8	204.989	3,343.89
59 5/8	187.318	2,792.21	65 3/8	205.382	3,356.71
59 6/8	187.711	2,803.93	65 4/8	205.775	3,369.56
59 7/8	188.103	2,815.67	65 5/8	206.167	3,382.44
60	188.496	2,827.44	65 6/8	206.560	3,395.33
60 1/8	188.889	2,839.23	65 7/8	206.953	3,408.26
60 2/8	189.281	2,851.05	66	207.346	3,421.20
60 3/8	189.674	2,862.89	66 1/8	207.738	3,434.17
60 4/8	190.067	2,874.76	66 2/8	208.131	3,447.17
60 5/8	190.459	2,886.65	66 3/8	208.524	3,460.19
60 6/8	190.852	2,898.57	66 4/8	208.916	3,473.24
60 7/8	191.245	2,910.51	66 5/8	209.309	3,486.30
61	191.638	2,922.47	66 6/8	209.702	3,499.40
61 1/8	192.030	2,934.46	66 7/8	210.094	3,512.52
61 2/8	192.423	2,946.48	67	210.487	3,525.66
61 3/8	192.816	2,958.52	67 1/8	210.880	3,538.83
61 4/8	193.208	2,970.58	67 2/8	211.273	3,552.02

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
67⅛	211.665	3,565.24	73⅛	229.729	4,199.74
67¼	212.058	3,578.48	73¼	230.122	4,214.11
67⅜	212.451	3,591.74	73⅜	230.515	4,228.51
67½	212.843	3,605.04	73½	230.908	4,242.93
67⅞	213.236	3,618.35	73⅝	231.300	4,257.37
68	213.629	3,631.69	73¾	231.693	4,271.84
68⅛	214.021	3,645.05	73⅞	232.086	4,286.33
68¼	214.414	3,658.44	74	232.478	4,300.85
68⅜	214.807	3,671.86	74⅛	232.871	4,315.39
68½	215.200	3,685.29	74¼	233.264	4,329.96
68⅝	215.592	3,698.76	74⅜	233.656	4,344.55
68¾	215.985	3,712.24	74½	234.049	4,359.17
68⅞	216.378	3,725.75	74⅝	234.442	4,373.81
69	216.770	3,739.29	74¾	234.835	4,388.47
69⅛	217.163	3,752.85	74⅞	235.227	4,403.16
69¼	217.556	3,766.43	75	235.620	4,417.87
69⅜	217.948	3,780.04	75⅛	236.013	4,432.61
69½	218.341	3,793.68	75¼	236.405	4,447.38
69⅝	218.734	3,807.34	75⅜	236.798	4,462.16
69¾	219.127	3,821.02	75½	237.191	4,476.98
69⅞	219.519	3,834.73	75⅝	237.583	4,491.81
70	219.912	3,848.46	75¾	237.976	4,506.67
70⅛	220.305	3,862.22	75⅞	238.369	4,521.56
70¼	220.697	3,876.00	76	238.762	4,536.47
70⅜	221.090	3,889.80	76⅛	239.154	4,551.41
70½	221.483	3,903.63	76¼	239.547	4,566.36
70⅝	221.875	3,917.49	76⅜	239.940	4,581.35
70¾	222.268	3,931.37	76½	240.332	4,596.36
70⅞	222.661	3,945.27	76⅝	240.725	4,611.39
71	223.054	3,959.20	76¾	241.118	4,626.45
71⅛	223.446	3,973.15	76⅞	241.510	4,641.53
71¼	223.839	3,987.13	77	241.903	4,656.64
71⅜	224.232	4,001.13	77⅛	242.296	4,671.77
71½	224.624	4,015.16	77¼	242.689	4,686.92
71⅝	225.017	4,029.21	77⅜	243.081	4,702.10
71¾	225.410	4,043.29	77½	243.474	4,717.31
71⅞	225.802	4,057.39	77⅝	243.867	4,732.54
72	226.195	4,071.51	77¾	244.259	4,747.79
72⅛	226.588	4,085.66	77⅞	244.652	4,763.07
72¼	226.981	4,099.84	78	245.045	4,778.37
72⅜	227.373	4,114.04	78⅛	245.437	4,793.70
72½	227.766	4,128.26	78¼	245.830	4,809.05
72⅝	228.159	4,142.51	78⅜	246.223	4,824.43
72¾	228.551	4,156.78	78½	246.616	4,839.83
72⅞	228.944	4,171.08	78⅝	247.008	4,855.26
73	229.337	4,185.40	78¾	247.401	4,870.71

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
78 1/8	247.794	4,886.18	84 1/8	265.858	5,624.56
79	248.186	4,901.68	84 1/4	266.251	5,641.18
79 1/8	248.579	4,917.21	84 3/8	266.643	5,657.84
79 1/4	248.972	4,932.75	85	267.036	5,674.51
79 3/8	249.364	4,948.33	85 1/8	267.429	5,691.22
79 1/2	249.757	4,963.92	85 1/4	267.821	5,707.94
79 5/8	250.150	4,979.55	85 3/8	268.214	5,724.69
79 3/4	250.543	4,995.19	85 1/2	268.607	5,741.47
79 7/8	250.935	5,010.86	85 5/8	268.999	5,758.27
80	251.328	5,026.56	85 3/4	269.392	5,775.10
80 1/8	251.721	5,042.28	85 7/8	269.785	5,791.94
80 1/4	252.113	5,058.03	86	270.178	5,808.82
80 3/8	252.506	5,073.79	86 1/8	270.570	5,825.72
80 1/2	252.899	5,089.59	86 1/4	270.963	5,842.64
80 5/8	253.291	5,105.41	86 3/8	271.356	5,859.59
80 3/4	253.684	5,121.25	86 1/2	271.748	5,876.56
80 7/8	254.077	5,137.12	86 5/8	272.141	5,893.55
81	254.470	5,153.01	86 3/4	272.534	5,910.58
81 1/8	254.862	5,168.93	86 7/8	272.926	5,927.62
81 1/4	255.255	5,184.87	87	273.319	5,944.69
81 3/8	255.648	5,200.83	87 1/8	273.712	5,961.79
81 1/2	256.040	5,216.82	87 1/4	274.105	5,978.91
81 5/8	256.433	5,232.84	87 3/8	274.497	5,996.05
81 3/4	256.826	5,248.88	87 1/2	274.890	6,013.22
81 7/8	257.218	5,264.94	87 5/8	275.283	6,030.41
82	257.611	5,281.03	87 3/4	275.675	6,047.63
82 1/8	258.004	5,297.14	87 7/8	276.068	6,064.87
82 1/4	258.397	5,313.28	88	276.461	6,082.14
82 3/8	258.789	5,329.44	88 1/8	276.853	6,099.43
82 1/2	259.182	5,345.63	88 1/4	277.246	6,116.74
82 5/8	259.575	5,361.84	88 3/8	277.629	6,134.08
82 3/4	259.967	5,378.08	88 1/2	278.032	6,151.45
82 7/8	260.360	5,394.34	88 5/8	278.424	6,168.84
83	250.753	5,410.62	88 3/4	278.817	6,186.25
83 1/8	261.145	5,426.93	88 7/8	279.210	6,203.69
83 1/4	261.538	5,443.26	89	279.602	6,221.15
83 3/8	261.931	5,459.62	89 1/8	279.995	6,238.64
83 1/2	262.324	5,476.01	89 1/4	280.388	6,256.15
83 5/8	262.716	5,492.41	89 3/8	280.780	6,273.69
83 3/4	263.109	5,508.84	89 1/2	281.173	6,291.25
83 7/8	263.502	5,525.30	89 5/8	281.566	6,308.84
84	263.894	5,541.78	89 3/4	281.959	6,326.45
84 1/8	264.287	5,558.29	89 7/8	282.351	6,344.08
84 1/4	264.680	5,574.82	90	282.744	6,361.74
84 3/8	265.072	5,591.37	90 1/8	283.137	6,379.42
84 1/2	265.465	5,607.95	90 1/4	283.529	6,397.13

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TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
90⅛	283.922	6,414.86	95¼	299.237	7,125.59
90¼	284.315	6,432.62	95⅜	299.630	7,144.31
90⅜	284.707	6,450.40	95½	300.023	7,163.04
90½	285.100	6,468.21	95⅝	300.415	7,181.81
90⅝	285.493	6,486.04	95¾	300.808	7,200.60
91	285.886	6,503.90	95⅞	301.201	7,219.41
91⅛	286.278	6,521.78	96	301.594	7,238.25
91¼	286.671	6,539.68	96⅛	301.986	7,257.11
91⅜	287.064	6,557.61	96¼	302.379	7,275.99
91½	287.456	6,575.56	96⅜	302.772	7,294.91
91⅝	287.849	6,593.54	96½	303.164	7,313.84
91¾	288.242	6,611.55	96⅝	303.557	7,332.80
91⅞	288.634	6,629.57	96¾	303.950	7,351.79
92	289.027	6,647.63	96⅞	304.342	7,370.79
92⅛	289.420	6,665.70	97	304.735	7,389.83
92¼	289.813	6,683.80	97⅛	305.128	7,408.89
92⅜	290.205	6,701.93	97¼	305.521	7,427.97
92½	290.598	6,720.08	97⅜	305.913	7,447.08
92⅝	290.991	6,738.25	97½	306.306	7,466.21
92¾	291.383	6,756.45	97⅝	306.699	7,485.37
92⅞	291.776	6,774.68	97¾	307.091	7,504.55
93	292.169	6,792.92	97⅞	307.484	7,523.75
93⅛	292.562	6,811.20	98	307.877	7,542.98
93¼	292.954	6,829.49	98⅛	308.270	7,562.24
93⅜	293.347	6,847.82	98¼	308.662	7,581.52
93½	293.740	6,866.16	98⅜	309.055	7,600.82
93⅝	294.132	6,884.53	98½	309.448	7,620.15
93¾	294.525	6,902.93	98⅝	309.840	7,639.50
93⅞	294.918	6,921.35	98¾	310.233	7,658.88
94	295.310	6,939.79	98⅞	310.626	7,678.28
94⅛	295.703	6,958.26	99	311.018	7,697.71
94¼	296.096	6,976.76	99⅛	311.411	7,717.16
94⅜	296.488	6,995.28	99¼	311.804	7,736.63
94½	296.881	7,013.82	99⅜	312.196	7,756.13
94⅝	297.274	7,032.39	99½	312.589	7,775.66
94¾	297.667	7,050.98	99⅝	312.982	7,795.21
94⅞	298.059	7,069.59	99¾	313.375	7,814.78
95	298.452	7,088.24	99⅞	313.767	7,834.38
95⅛	298.845	7,106.90	100	314.160	7,854.00

The preceding table may be used to determine the diameter when the circumference or area is known. Thus, the diameter of a circle having an area of 7,200 sq. in. is, approximately, 95¾ in.

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DECIMAL EQUIVALENTS OF PARTS OF ONE INCH.

1–64	.015625	17–64	.265625	33–64	.515625	49–64	.765625
1–32	.031250	9–32	.281250	17–32	.531250	25–32	.781250
3–64	.046875	19–64	.296875	35–64	.546875	51–64	.796875
1-16	.062500	5-16	.312500	9-16	.562500	13-16	.812500
5–64	.078125	21–64	.328125	37–64	.578125	53–64	.828125
3–32	.093750	11–32	.343750	19–32	.593750	27–32	.843750
7–64	.109375	23–64	.359375	39–64	.609375	55–64	.859375
1-8	.125000	3-8	.375000	5-8	.625000	7-8	.875000
9–64	.140625	25–64	.390625	41–64	.640625	57–64	.890625
5–32	.156250	13–32	.406250	21–32	.656250	29–32	.906250
11–64	.171875	27–64	.421875	43–64	.671875	59–64	.921875
3-16	.187500	7-16	.437500	11-16	.687500	15-16	.937500
13–64	.203125	29–64	.453125	45–64	.703125	61–64	.953125
7–32	.218750	15–32	.468750	23–32	.718750	31–32	.968750
15–64	.234375	31–64	.484375	47–64	.734375	63–64	.984375
1-4	.250000	1-2	.500000	3-4	.750000	1	1

DECIMALS OF A FOOT FOR EACH 1-32 OF AN INCH.

Inch.	0″	1″	2″	3″	4″	5″
0	0	.0833	.1667	.2500	.3333	.4167
1/32	.0026	.0859	.1693	.2526	.3359	.4193
1/16	.0052	.0885	.1719	.2552	.3385	.4219
3/32	.0078	.0911	.1745	.2578	.3411	.4245
1/8	.0104	.0937	.1771	.2604	.3437	.4271
5/32	.0130	.0964	.1797	.2630	.3464	.4297
3/16	.0156	.0990	.1823	.2656	.3490	.4323
7/32	.0182	.1016	.1849	.2682	.3516	.4349
1/4	.0208	.1042	.1875	.2708	.3542	.4375
9/32	.0234	.1068	.1901	.2734	.3568	.4401
5/16	.0260	.1094	.1927	.2760	.3594	.4427
11/32	.0286	.1120	.1953	.2786	.3620	.4453
3/8	.0312	.1146	.1979	.2812	.3646	.4479
13/32	.0339	.1172	.2005	.2839	.3672	.4505
7/16	.0365	.1198	.2031	.2865	.3698	.4531
15/32	.0391	.1224	.2057	.2891	.3724	.4557
1/2	.0417	.1250	.2083	.2917	.3750	.4583
17/32	.0443	.1276	.2109	.2943	.3776	.4609
9/16	.0469	.1302	.2135	.2969	.3802	.4635
19/32	.0495	.1328	.2161	.2995	.3828	.4661
5/8	.0521	.1354	.2188	.3021	.3854	.4688
21/32	.0547	.1380	.2214	.3047	.3880	.4714
11/16	.0573	.1406	.2240	.3073	.3906	.4740
23/32	.0599	.1432	.2266	.3099	.3932	.4766

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TABLE—(*Continued*).

Inch.	0″	1″	2″	3″	4″	5″
1/64	.0625	.1458	.2292	.3125	.3958	.4792
1/32	.0651	.1484	.2318	.3151	.3984	.4818
3/64	.0677	.1510	.2344	.3177	.4010	.4844
1/16	.0703	.1536	.2370	.3203	.4036	.4870
5/64	.0729	.1562	.2396	.3229	.4062	.4896
3/32	.0755	.1589	.2422	.3255	.4089	.4922
7/64	.0781	.1615	.2448	.3281	.4115	.4948
1/8	.0807	.1641	.2474	.3307	.4141	.4974

DECIMALS OF A FOOT FOR EACH 1-32 OF AN INCH.

Inch.	6″	7″	8″	9″	10″	11″
0	.5000	.5833	.6667	.7500	.8333	.9167
1/64	.5026	.5859	.6693	.7526	.8359	.9193
1/32	.5052	.5885	.6719	.7552	.8385	.9219
3/64	.5078	.5911	.6745	.7578	.8411	.9245
1/16	.5104	.5937	.6771	.7604	.8437	.9271
5/64	.5130	.5964	.6797	.7630	.8464	.9297
3/32	.5156	.5990	.6823	.7656	.8490	.9323
7/64	.5182	.6016	.6849	.7682	.8516	.9349
1/8	.5208	.6042	.6875	.7708	.8542	.9375
9/64	.5234	.6068	.6901	.7734	.8568	.9401
5/32	.5260	.6094	.6927	.7760	.8594	.9427
11/64	.5286	.6120	.6953	.7786	.8620	.9453
3/16	.5312	.6146	.6979	.7812	.8646	.9479
13/64	.5339	.6172	.7005	.7839	.8672	.9505
7/32	.5365	.6198	.7031	.7865	.8698	.9531
15/64	.5391	.6224	.7057	.7891	.8724	.9557
1/4	.5417	.6250	.7083	.7917	.8750	.9583
17/64	.5443	.6276	.7109	.7943	.8776	.9609
9/32	.5469	.6302	.7135	.7969	.8802	.9635
19/64	.5495	.6328	.7161	.7995	.8828	.9661
5/16	.5521	.6354	.7188	.8021	.8854	.9688
21/64	.5547	.6380	.7214	.8047	.8880	.9714
11/32	.5573	.6406	.7240	.8073	.8906	.9740
23/64	.5599	.6432	.7266	.8099	.8932	.9766
3/8	.5625	.6458	.7292	.8125	.8958	.9792
25/64	.5651	.6484	.7318	.8151	.8984	.9818
13/32	.5677	.6510	.7344	.8177	.9010	.9844
27/64	.5703	.6536	.7370	.8203	.9036	.9870
7/16	.5729	.6562	.7396	.8229	.9062	.9896
29/64	.5755	.6589	.7422	.8255	.9089	.9922
15/32	.5781	.6615	.7448	.8281	.9115	.9948
31/64	.5807	.6641	.7474	.8307	.9141	.9974

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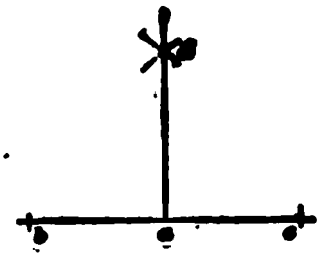
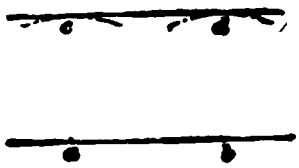
GEOMETRICAL DRAWING.

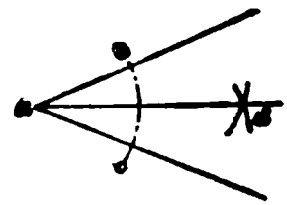
To erect a perpendicular to the line b c at the point a. With *a* as a center, and any radius, as *a b*, strike arcs cutting the line at *b* and *c*. From *b* and *c* as centers, and any radius greater than *b a*, strike arcs intersecting at *d*. Draw *d a*, which will be perpendicular to *b c* at *a*.

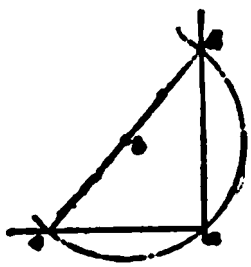




To draw a line parallel to a b. At any points *a* and *b*, with a radius equal to the required distance between the lines, draw arcs at *c* and *d*. The line *c d*, tangent to the arcs, will be the required parallel.

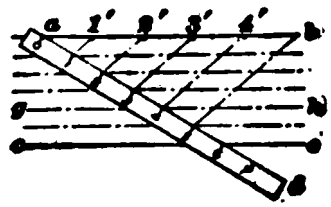
To bisect the angle b a c. With *a* as a center, strike an arc cutting the sides of the angle in *b* and *c*. With *b* and *c* as centers, and any radius, strike arcs intersecting, as at *d*. Draw *d a*, the bisector.





To erect a perpendicular at the end of a line. Take a center anywhere above the line, as at *b*. Strike an arc passing through *a* and cutting the given line at *c*. Draw a line through *c* and *b*, cutting the arc at *d*. Draw the line *a d*, which will be the required perpendicular.

To divide a line into any number of equal parts. Let it be required to divide the line *a b* into 5 equal parts. Draw any line *a d*, and point off 5 equal divisions, as shown. From *5* draw a line to *b* and draw *4–4'*, *3–3'*, etc. parallel to *5 b*.



To divide a space between two parallel lines or surfaces (for example, the spacing of risers in a stairway). Draw *a b* and *c e* the given distance apart. Then move a scale along them, until as many spaces are included along *a d* as there are number of divisions required. Mark the points *1, 2, 3*, etc., and draw lines through them parallel to *a b* and *c e*.

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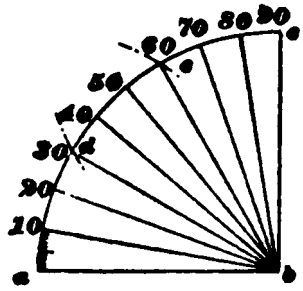
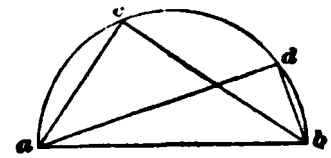
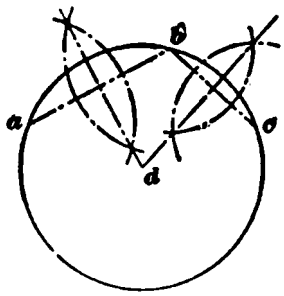


The magnitude of an angle depends not upon the length of its sides, but upon the number of degrees contained in the arc of a circle drawn with the vertex as a center. The circle is divided into 360 equal parts, called *degrees*. To divide a quadrant as shown in the figure, first divide it into 3 parts by the arcs at *e* and *d*, chords *c d* and *a e* being equal to the radius. Then subdivide with dividers.

An *inscribed* angle has its vertex (as *c* or *d*) in the circumference of a circle. Any angle inscribed in a semicircle is a right angle, as *a c b*, or *a d b*.

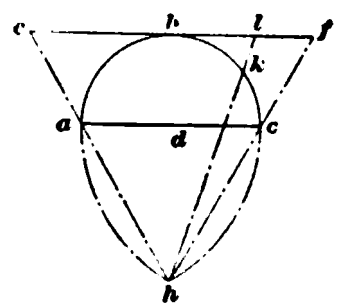


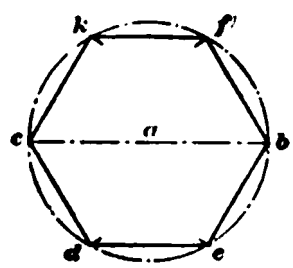
To draw a circle through three points not in a straight line, as *a*, *b*, and *c*. Bisect *a b* and also *b c*. The two bisectors will intersect in a point *d*, which will be the center of the required circle.



To find the center of a circular arc, as *a b c*, take a point, as *b* on the curve, and draw *b a* and *b c*. Bisect these lines by perpendiculars; the intersection *d* will be the required center.

To find a straight line nearly equal to a semi-circumference, as *a b c*. On the diameter construct the equilateral triangle *a c h*. Through *a* and *c* draw *h e* and *h f*. Then *e f* is the length of the semi-circumference. Draw any line, as *h k l*; then *l f* is almost exactly the length of arc *k c*, and *b l* that of arc *b k*.





To construct a hexagon from a given side. Describe a circle with a radius *a b* equal to the given side. Draw a diameter as *c b*. From *c* and *b* as centers, and a radius equal to the given side, draw arcs cutting the circle at *k*, *d*, *f*, and *e*. Connect *c*, *k*, *f*, *b*, *e*, and *d*.

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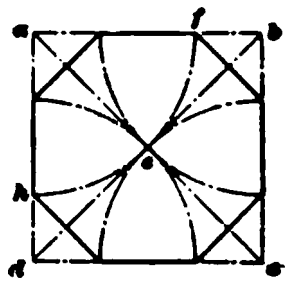
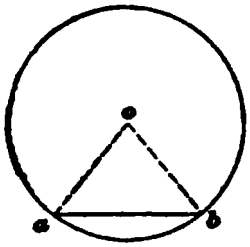
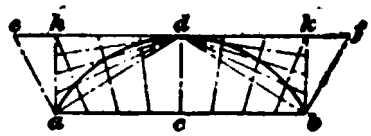
To inscribe an octagon in a square. Draw the diagonals *a c* and *b d*. With *a* as a center, and *a e* as a radius, strike an arc cutting the sides of the square at *f* and *h*. Repeat the operation at *b*, *c*, and *d*, and draw lines connecting the eight points thus found to form the figure required.



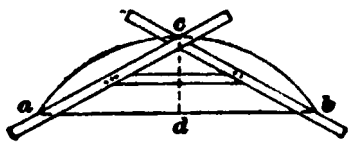
To draw any regular polygon in a circle. Divide 360° by the number of sides; the quotient will be the angle *a o b*. Lay off this angle at the center with a protractor, and draw its chord, a side of the required polygon. Step this side around on the circumference, and connect the points found.



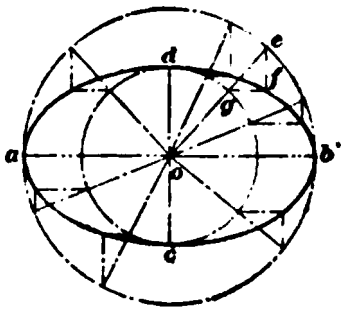
To draw a segment of a circle, having given the chord a b and height c d. Draw *e f*, through *d*, parallel to *a b*; also, *a d* and *d b*. Draw *a e* and *b f* perpendicular to *a d* and *d b*; also *a h* and *b k* perpendicular to *a b*. Divide *e d*, *d f*, *a c*, *c b*, *a h*, and *b k* into the same number of equal parts. Draw lines connecting the points as shown, and trace the curve through the intersections.



To draw a segment of a circle by means of a fixed triangle. Let *a b* be the required chord, and *d c* the rise. Drive nails at *a* and *b*. Make a triangle, as shown, from thin strips, so that the vertex comes at *c*, and stiffen it with the cross-brace. Now, by moving the triangle, always keeping the sides touching the nails at *a* and *b*, the arc may be traced by a pencil held at *c*.



To draw an ellipse, having given the axes. Draw concentric circles whose diameters are equal to the axes *a b* and *c d*. From *o* draw any radius, as *o e*. From *g*, where *o e* cuts the inner circle, draw *g f* parallel to the major axis *a b*. From *e*, draw *e f* parallel to the minor axis *d c*. The intersection *f* gives a point on the ellipse. Other points are similarly found.



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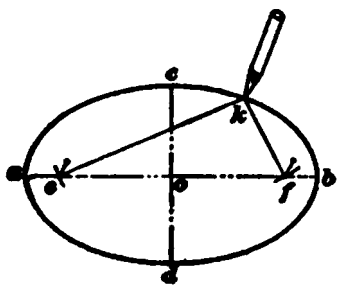
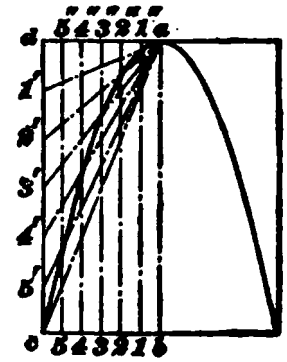
To draw an ellipse with a string, having given the axes a b and c d. With *c* as a center, and a radius equal to *o b*, strike arcs cutting the major axis at *e* and *f*, the foci of the ellipse. Stick pins at *e* and *f*, and attach a string as shown, the length of the string being equal to the length of the major axis. Keep the string stretched with a pencil point, and sweep around the ellipse.



To draw a parabola. Having given the coordinates *a b* and *b c*, to draw a parabola, complete the rectangle *a b c d*. Divide *b c* and *c d* into the same number of equal parts. From *1'*, *2'*, *3'*, etc., draw lines through *a*. Through *1*, *2*, *3*, etc., draw lines parallel to *a b*. The intersections of *1' a* and *1-1''*, of *2' a* and *2-2''*, etc. are points on the required parabola.



LAYING OUT ANGLES.

By Two-Foot Rule.—To lay off any angle given in the table, open the rule at the middle until the distance between the inside corners at the knuckle joints (6-inches mark) is equal to the distance given for that angle under *Chord*.

Degrees.	Chord. Inches.	Degrees.	Chord. Inches.
5	$\frac{17}{32}$	50	$5\frac{1}{16}$
10	$1\frac{1}{32}$	55	$5\frac{17}{32}$
15	$1\frac{9}{32}$	60	6
20	$2\frac{1}{32}$	65	$6\frac{7}{16}$
25	$2\frac{9}{32}$	70	$6\frac{7}{8}$
30	$3\frac{3}{32}$	75	$7\frac{5}{16}$
35	$3\frac{11}{32}$	80	$7\frac{23}{32}$
40	$4\frac{3}{32}$	85	$8\frac{1}{8}$
45	$4\frac{19}{32}$	90	$8\frac{1}{2}$

To lay off an angle greater than 90°, subtract the angle from 180°; lay out the latter angle, extending one side.

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BLUEPRINTS.

Plumbers and fitters' drawings are usually blueprints. They are copies of drawings of the plumbing or heating system made on tracing cloth.

Blueprint paper for copying tracings of plans and other drawings may be prepared as follows: Dissolve 1 oz. avoirdupois, of ammonia citrate of iron in 6 oz. of water, and in a separate bottle dissolve the same quantity of potassium ferricyanide in 6 oz. of water. Keep these solutions separate, and in a dark place, or in opaque bottles.

To prepare the paper, mix equal quantities of the two solutions, and with a sponge spread it evenly over the surface. Let the paper remain in a horizontal position until the chemical has set on the surface, which will take but a few minutes; then hang the paper up to dry. In preparing the paper darken the room by pulling down the shades, as direct rays of light affect sensitized surfaces. The prepared paper should be kept in a closed drawer, well covered with heavy paper, so that no light can come in contact with the sensitized surface; otherwise it will lose much of its value.

To make a blueprint from a tracing, lay the tracing with ink side down against the glass of the printing frame, then take the prepared paper, and place the sensitized surface down on the tracing. On the top of the paper place the felt cushion, on top of which place the hinged back of the printing frame, after which expose to the sunlight. The exposure will vary in sunlight from about 3 to 10 minutes. After the exposure, wash the paper thoroughly in a trough of cold water for about 10 minutes, and hang it up to dry.

The print after washing should be of a deep-blue color, with clear white lines. If the color is a pale blue, this indicates that the print has not had sufficient exposure, and if the lines of the drawing are not perfectly clear and white, that the exposure has been too long.

Corrections may be made on the print with an ordinary writing or ruling pen and a solution of washing soda, caustic potash, strong ammonia, or any other alkali. When any of these are mixed with carmine ink, the marks on the print will be red, thus making the corrections clear.

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MECHANICS.

FALLING BODIES.

Let $g = 32.16$ = constant acceleration due to the attraction of the earth;

t = number of seconds that the body falls;

v = velocity in feet per second at the end of the time t;

h = distance that the body falls during the time t.

Then, $$v = g\,t = \frac{2\,h}{t} = \sqrt{2\,g\,h} = 8.02\ \sqrt{h}.$$

$$h = \frac{v\,t}{2} = \frac{g\,t^2}{2} = \frac{v^2}{2\,g} = .015547\ v^2.$$

$$t = \frac{v}{g} = \frac{2\,h}{v} = \sqrt{\frac{2\,h}{g}} = .24938\ \sqrt{h}.$$

CENTRIFUGAL FORCE.

F = centrifugal force in pounds;

W = weight of revolving body in pounds;

r = distance from the axis of motion to the center of gravity of the body in feet;

N = number of revolutions per minute;

v = velocity in feet per second.

$$F = \frac{W\,v^2}{g\,r} = .00034\ W\,r\,N^2.$$

In calculating the centrifugal force of flywheels, it is customary to neglect the arms and take r equal to the mean radius of the rim; in such cases W is taken as one-half the weight of the rim. The result thus obtained, divided by π is approximately the force tending to burst the flywheel rim.

EXAMPLE.—What is the force tending to burst a flywheel rim weighing 7 tons, making 150 rev. per min., and having a mean radius of 5 ft.?

SOLUTION.—

$$F = \frac{.00034 \times (\frac{1}{2} \times 7 \times 2{,}000) 5 \times 150^2}{3.1416} = 85{,}227\ \text{lb.}$$

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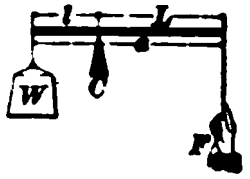
MECHANICAL POWERS.

$F : W = l : L.$ $F L = W l.$

$$F = \frac{W l}{L}. \qquad W = \frac{F L}{l}.$$

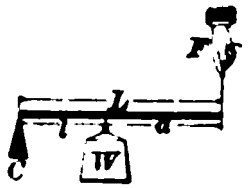
$$l = \frac{F a}{W + F}. \qquad L = \frac{W a}{W + F}.$$



$F : W = l : L.$ $F L = W l.$

$$F = \frac{W l}{L}. \qquad W = \frac{F L}{l}.$$

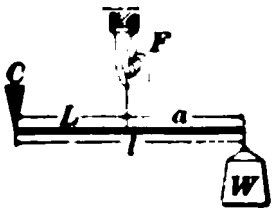
$$L = \frac{W a}{W - F}. \qquad l = \frac{F a}{W - F}.$$



$F : W = l : L.$ $F L = W l.$

$$F = \frac{W l}{L}. \qquad W = \frac{F L}{l}.$$

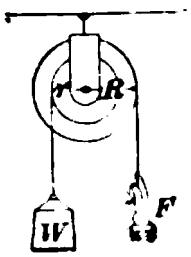
$$L = \frac{W a}{F - W}. \qquad l = \frac{F a}{F - W}.$$



$F : W = r : R.$ $F R = W r.$

$$F = \frac{W r}{R}. \qquad R = \frac{W r}{F}.$$

$$W = \frac{R F}{r}. \qquad r = \frac{R F}{W}.$$



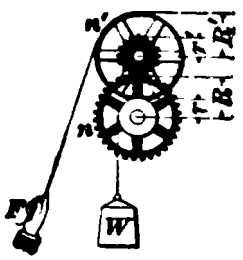
$$F = \frac{W r r'}{R R'}. \qquad W = \frac{F R R'}{r r'}.$$

n = number of revolutions of large gear.

$$n : n' = r' : R.$$

$$v : v' = r r' : R R'.$$

v = velocity of W; v' = velocity of F.



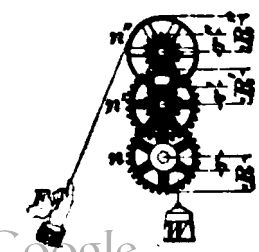
$$F = \frac{W r r' r''}{R R' R''}. \qquad W = \frac{F R R' R''}{r r' r''}.$$

$$n : n'' = r' r'' : R R'.$$

$$v : v' = r r' r'' : R R' R''.$$

r, r', r'', etc. = radii of the pinions;

R, R', R'', etc. = radii of the wheels.



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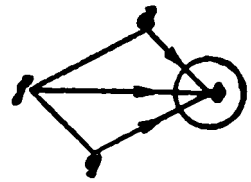
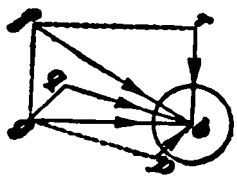
Let db and qb represent the magnitudes and directions of two forces that act to move the body b. By completing the parallelogram there will be obtained a diagonal force fb, whose magnitude and direction are equal to the effect produced by db and qb. fb is called the resultant of db and qb.



If three or more forces act in different directions to move a body b, find the resultant of any two of them, and consider it as a single force. Between this and the next force find a second resultant. Thus, pb, qb, and rb are magnitudes and directions of the forces. $pb + qb + rb = gb + rb = fb$, the magnitude and direction of the three forces, pb, qb, and rb.

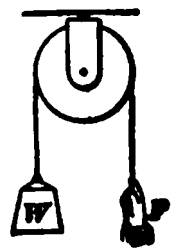


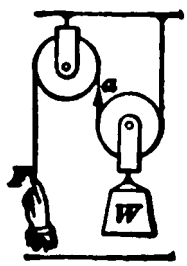
A SINGLE FIXED PULLEY.

$$F = W.$$

$$v = v'.$$

v = velocity of W; v' = velocity of F.





A SINGLE MOVABLE PULLEY.

$F : W = 1 : 2$, or $F = \frac{1}{2} W$.

If the force F be applied at a and act upwards, the result will be the same.

$$v' = 2v.$$

v = velocity of W; v' = velocity of F.

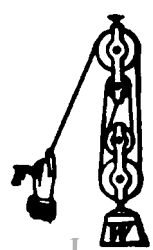
A DOUBLE MOVABLE PULLEY.

$F : W = 1 : 4$, or $F = \frac{1}{4} W$.

Let u = number of parts of rope, not counting the free end.

$$F = W + u. \quad v : v' = 1 : u.$$

v = velocity of W; v' = velocity of F.



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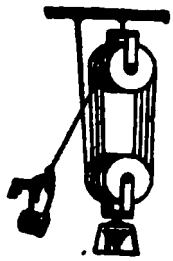


QUADRUPLE MOVABLE PULLEY.

$F = \frac{1}{8} W$. $F : W = 1 : 8$.

Let u = number of parts of rope, not counting the free end; then,

$F = W \div u$. $v : v' = 1 : u$.

v = velocity of W; v' = velocity of F.

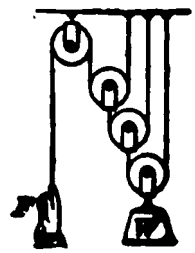
COMPOUND PULLEY.

u = number of movable pulleys.

$$F = \frac{W}{2^u}. \qquad W = 2^u F.$$

$$v : v' = 1 : 2^u.$$

v = velocity of W; v' = velocity of F.



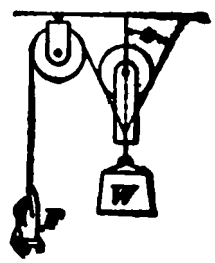
DIFFERENTIAL PULLEY.

$$W = \frac{2PR}{R - r}.$$

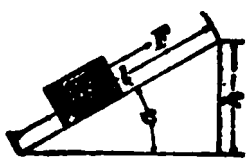
AN OBLIQUE FIXED PULLEY.

$F : W = 1 : 2 \cos z$.

$$W = 2F \cos z. \quad F = \frac{W}{2 \cos z}.$$



INCLINED PLANE.



$$F = \frac{Wh}{l} = W \sin a.$$

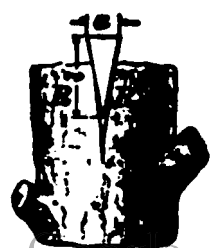
$$W = \frac{Fl}{h} = \frac{F}{\sin a}.$$

WEDGE.

F = force required to drive the wedge;

R = resistance.

$$F = \frac{Ra}{l}. \qquad R = \frac{Fl}{a}.$$



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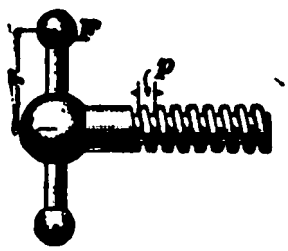

SCREW.

P = pitch of the screw;

r = radius on which the force F acts.

$$F : W :: P : 2\pi r.$$

$$F = \frac{WP}{2\pi r}. \qquad W = \frac{2\pi r F}{P}.$$

HYDROMECHANICS.

HYDROSTATICS.

Hydrostatics treats of liquids at rest under the action of forces. If a liquid is acted on by a pressure, the pressure per unit of area exerted anywhere on the mass of liquid is transmitted undiminished in all directions, and acts with the same force on all surfaces, in a direction at right angles to those surfaces.

General Law for the Downward Pressure on the Bottom of Any Vessel.—The pressure on the bottom of a vessel containing a liquid is independent of the shape of the vessel, and is equal to the weight of a prism of the liquid whose base is the same as the bottom of the vessel, and whose altitude is the distance between the bottom and the upper surface of the liquid, plus the pressure per unit of area upon the upper surface of the liquid multiplied by the area of the bottom of the vessel.

General Law for Upward Pressure.—The upward pressure on any submerged horizontal surface equals the weight of a prism of the liquid whose base has an area equal to the area of the submerged surface, and whose altitude is the distance between the submerged surface and the upper surface of the liquid, plus the pressure per unit of area on the upper surface of the liquid multiplied by the area of the submerged surface.

General Law for Lateral Pressure.—The pressure on any vertical surface due to the weight of the liquid is equal to the weight of a prism of the liquid whose base has the same area as the vertical surface, and whose altitude is the depth of the center of gravity of the vertical surface below the level of the liquid. Any additional pressure is to be added.

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Pressure on Oblique Surfaces.—The pressure exerted by a liquid in any direction on a plane surface is equal to the weight of a prism of the liquid whose base is the projection of the surface at right angles to the given direction, and whose height is the depth of the center of gravity of the surface below the level of the liquid.

If a cylinder is filled with water, and a pressure applied, the total pressure on any half section of the cylinder is equal to the projected area of the half cylinder (or the diameter multiplied by the length of the cylinder) multiplied by the depth of the center of gravity of the half cylinder, multiplied by the weight of a cubic inch of water, plus the diameter of the shell, multiplied by the pressure per square inch, multiplied by the length of the cylinder.

If d = the diameter, and l = the length of the cylinder, the pressure due to the weight of the water when the cylinder is vertical upon the half cylinder $= d \times l \times \frac{l}{2} \times$ the weight of a cubic inch of water $= d \times \frac{r^2}{2} \times$ the weight of a cubic inch of water; d and l are to be measured in inches.

The pressure in pounds per square inch due to a head of water is equal to the head in feet multiplied by .434.

The head equals the pressure in pounds per square inch multiplied by 2.304.

EXAMPLE.—(a) What is the pressure per square inch corresponding to a head of water of 175 ft.? (b) If the pressure had been 90 lb. per sq. in., what would the head have been?

SOLUTION.—(a) $175 \times .434 = 75.95$ lb. per sq. in.

(b) $90 \times 2.304 = 207.36$ ft.

HYDROKINETICS.

Hydrokinetics, also called hydrodynamics and hydraulics, treats of water in motion. When water flows in a pipe, conduit, or channel of any kind, the velocity is not the same at all points of the flow, unless all cross-sections of the pipe or channel are equal. That velocity which, being multiplied by the area of the cross-section of the stream, will equal the total quantity discharged, is called the *mean velocity*.

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Let Q = quantity that passes any section in 1 second;
A = area of the section;
v = mean velocity in feet per second.

Then, $$Q = A\,v, \text{ and } v = \frac{Q}{A}.$$

The vertical distance between the level surface of the water and the center of the aperture through which it flows, is called the *head.*

Let V = mean velocity of efflux through a small aperture;
h = head in feet at the center of the aperture;
w = weight of water flowing through the aperture per second.

Then, $V = \sqrt{2gh}$; that is, the velocity of efflux is the same as if the water had fallen through a height equal to the head.

Let Q = theoretical number of cubic feet discharged per second;
V_m = mean velocity through orifice in feet per second;
A = area of orifice;
h = theoretical head necessary to give a mean velocity V_m;
Q_a = actual quantity discharged in cubic feet per second.

Then, for an orifice in a thin plate, or a square-edged orifice (the hole itself may be of any shape, triangular, square, circular, etc., but the edges must not be rounded), the actual quantity discharged is

$$Q_a = .615\,Q = .615\,A\,V_m.$$

The *weir* is a device used for measuring the discharge of water. It is a retangular orifice through which the water flows.

If d = the depth of the opening in feet, and b its breadth in feet, the area of the opening is $A = d \times b$, and the theoretical discharge is $Q = d \times b \times V_m = db \times \frac{2}{3}\sqrt{2gd}$, the head for this case being taken as d.

The actual discharge when the top of the weir lies at the surface of the water is

$Q_a = .615\,Q = .615 \times db \times \frac{2}{3}\sqrt{2gd} = .615 \times \frac{2}{3}\,b\,\sqrt{2gd^3} = 3.268\,b\,\sqrt{d^3}$.

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If h_1 is the depth in feet of the top of a weir below the surface of the water, and h is the depth in feet of the bottom of the weir below the surface of the water, the actual discharge Q_a, in cubic feet per second, is

$$Q_a = .615 \times \tfrac{2}{3}\, b \sqrt{2g}\,(\sqrt{h^3} - \sqrt{h_1^3}) = 3.288\, b\,(\sqrt{h^3} - \sqrt{h_1^3}).$$

FLOW OF WATER IN PIPES.

Let V_m = mean velocity of discharge in feet per second;
h = total head in feet = vertical distance between the level of water in reservoir and the point of discharge;
l = length of pipe in feet;
d = diameter of pipe in inches;
f = coefficient of friction.

Then, for straight cylindrical pipes of uniform diameter, the mean velocity of efflux may be calculated by the formula,

$$V_m = 2.315 \sqrt{\frac{h\,d}{f\,l + 125\,d}}. \qquad (a)$$

NOTE.—The head is always taken as the vertical distance between the point of discharge and the level of the water at the source, or point from which it is taken, and is always measured in feet. It matters not how long the pipe is—whether vertical or inclined, whether straight or curved, nor whether any part of the pipe goes below the level of the point of discharge or not—the head is always measured as stated above.

EXAMPLE.—What is the mean velocity of efflux from a 6″ pipe, 5,780 ft. long, if the head is 170 ft.? Take $f = .021$.

SOLUTION.—

$$V_m = 2.315 \sqrt{\frac{h\,d}{f\,l + .125\,d}} = 2.315 \sqrt{\frac{170 \times 6}{.021 \times 5{,}780 + (.125 \times 6)}}$$

= 6.69 ft. per sec.

When the pipe is very long compared with the diameter, as in the above example, the following formula may be used:

$$V_m = 2.315 \sqrt{\frac{h\,d}{f\,l}}, \qquad (b)$$

in which the letters have the same meaning as in the preceding formula. This formula may be used when the length of the pipe exceeds 10,000 times its diameter.

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The actual head necessary to produce a certain velocity V_m may be calculated by the formula

$$h = \frac{f\,l\,V_m^2}{5.36\,d} + .0233\,V_m^2. \qquad (c)$$

If the head, the length of the pipe, and the diameter of the pipe are given, to find the discharge, use the formula

$$Q = .09445\,d^2\sqrt{\frac{h\,d}{f\,l + .125\,d}}; \qquad (d)$$

that is, the discharge in gallons per second equals .09445 times the square of the diameter of the pipe in inches, multiplied by the square root of the head in feet, multiplied by the diameter of the pipe in inches, divided by the coefficient of friction times the length of the pipe in feet, plus .125 times the diameter of the pipe in inches.

To find the value of f, calculate V_m by formula (b) assuming that $f = .025$, and get the final value of f from the following table:

V_m	f	V_m	f	V_m	f
.1	.0686	.7	.0349	2	.0265
.2	.0527	.8	.0336	3	.0243
.3	.0457	.9	.0325	4	.0230
.4	.0415	1	.0315	6	.0214
.5	.0387	1¼	.0297	8	.0205
.6	.0365	1½	.0284	12	.0193

EXAMPLE.—The length of a pipe is 6,270 ft., its diameter is 8 in. and the total head at the point of discharge is 215 ft. How many gallons are discharged per minute?

SOLUTION.—

$$V_m = 2.315\sqrt{\frac{215 \times 8}{.025 \times 6{,}270}} = 7.67 \text{ ft. per sec., nearly.}$$

Using the value of $f = .0205$ for $V_m = 8$ (see table), $Q =$

$$.09455 \times 8^2\sqrt{\frac{215 \times 8}{.0205 \times 6{,}270 + (.125 \times 8)}} = 22.03 \text{ gal. per sec.} =$$

$22.03 \times 60 = 1{,}321\,8$ gal. per min.

If it is desired to find the head necessary to give a discharge of a certain number of gallons per second through a pipe

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whose length and diameter are known, calculate the mean velocity of efflux by using the formula

$$V_m = \frac{24.51\ Q}{d^2}; \qquad (e)$$

find the value of f from the table, corresponding to this value of V_m, and substitute these values of f and V_m in the formula for the head.

EXAMPLE.—A 4″ pipe, 2,000 ft. long, is to discharge 24,000 gal. of water per hr.; what head is necessary?

SOLUTION.— $\frac{24{,}000}{60 \times 60} = 6\frac{2}{3}$ gal. per sec. $V_m = \frac{24.51 \times 6\frac{2}{3}}{4^2}$ = 10.2 ft. per sec.

From the table, $f = .0205$ for $V_m = 8$, and .0193 for $V_m = 12$; assume that $f = .02$ for $V_m = 10.2$.

Then, $h = \frac{.02 \times 2{,}000 \times 10.2^2}{5.36 \times 4} + .0233 \times 10.2^2 = 196.53$ ft.

To find the diameter of a pipe that will give any required discharge in gallons per second, the total length of the pipe and the head being known, *find the value of d by formula* (f); *substitute this value in formula* (e), *and find the value of* V_m. *Then find from the table the value of f corresponding to this value of* V_m. *Substitute the values of d and f just found in the right-hand member of formula* (g) *and solve for d; the result will be the diameter of the pipe, accurate enough for all practical purposes.*

$$d = 1.229\sqrt[5]{\frac{l\,Q^2}{h}}. \qquad (f) \qquad d = 2.57\sqrt[5]{\frac{(fl + \frac{1}{3}d)\,Q^2}{h}}. \qquad (g)$$

EXAMPLE.—A pipe 2,000 ft. long is required to discharge 24,000 gal. of water per hr. The head being 195 ft., what should be the diameter of the pipe?

SOLUTION. — $Q = \frac{24{,}000}{60 \times 60} = 6\frac{2}{3}$ gal. per sec. Substituting in formula (f), $d = 1.229\sqrt[5]{\frac{2{,}000 \times (6\frac{2}{3})^2}{195}} = 4.18+$ in. Substituting this value in formula (e), $V_m = \frac{24.51 \times 6\frac{2}{3}}{4.18^2} =$ 9.352 ft. per. sec. From the table, the value of f for $V_m = 9.352$ is .0201. Substituting this value of f and the value of d, found above, in formula (g),

$d = 2.57\sqrt[5]{\frac{(.0201 \times 2{,}000 + \frac{1}{3} \times 4.18) \times (6\frac{2}{3})^2}{195}} = 4.01+$; say, 4 in.

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BUILDING CONSTRUCTION.

WEIGHTS.

APPROXIMATE WEIGHT OF BUILDING MATERIALS.

Material.	Average Weight. Lb. per Sq. Ft.
Glass, $\frac{1}{8}$ in. thick	1½
Hemlock sheathing, 1 in. thick	2
Lath-and-plaster ceiling (ordinary)	6–8
Neponset roofing felt, 2 layers	½
Spruce sheathing, 1 in. thick	2½
Slate, $\frac{1}{8}$ in. thick, 3 in. double lap	4½
Shingles, 6″ × 18″, $\frac{1}{3}$ to weather	2
Skylight of glass, $\frac{3}{16}$ to $\frac{1}{4}$ in., including frame	4–10
Slag roof, 4-ply	4
Tin, IX	¾
White-pine sheathing, 1 in. thick	2½
Yellow-pine sheathing, 1 in. thick	4

WEIGHT OF FLOORS, PARTITIONS, AND ROOFS.

Material.	Weight. Lb. per Sq. Ft.
Floors, including weight of beams—	
Wooden, in dwellings	10–15
Wooden, office buildings	25–30
Hollow-tile arch	70–90
Brick and concrete (broken stone)	100–130
Partitions—	
Wooden	15–20
Hollow tile	15–30
Roofs, including framing—	
Shingle	6–10
Tin	6–8
Slate	12–15
Tar and gravel	10–12
Corrugated iron	8–10
Tile	20–30

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APPROXIMATE WEIGHT OF FIREPROOF FLOORS.

(*Exclusive of Partitions.*)

Depth of I Beams.	Weight. Lb. per Sq. Ft. Including Beams.	
	Brick Arch.	Hollow Tile.
8	74	63–74
9	74	65–80
10	81	68–81
12	94	71–93
15	113	91–113

WEIGHT OF FIREPROOFING MATERIALS.

Kind.	Span. Ft.	Thickness. In.	Weight. Lb. per Sq. Ft.
Dense-tile flat arch	4–7	6–12	22–42
Porous-tile flat arch	3–10	6–15	21–43
Dense-tile partition		3–6	15–28
Porous-tile partition		3–6	14–27
Porous-tile ceiling		2–4	12–20
Porous-tile roofing		2–4	12–20

WIND PRESSURE.

Name of Wind.	Velocity. Mi. per Hr.	Pressure. Lb. per Sq. Ft.
Fresh breeze	10	.4
Stiff breeze	20	1.6
Strong wind	30	3.6
High wind	40	6.4
Storm	50	10.0
Violent storm	60	14.4
Hurricane	80	25.6
Violent hurricane	100	40.0

The wind pressure on a cylindrical surface is usually taken as one-half that on a flat surface of the same height and width.

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SAFE LOADS AND BREAKING LOADS.

The following table gives the safe working loads allowable in good practice for brickwork, masonry, and foundation soils; in other words, calculations may be based directly on the values given, without using any factor of safety.

SAFE BEARING LOADS.

Brick and Stone Masonry.	Lb. per Sq. In.
Brickwork.	
Bricks, hard, laid in lime mortar	100
Hard, laid in Portland cement mortar	200
Hard, laid in Rosendale cement mortar	150
Masonry.	
Granite, capstone	700
Squared stonework	350
Sandstone, capstone	350
Squared stonework	175
Rubble stonework, laid in lime mortar	80
Rubble stonework, laid in cement mortar	150
Limestone, capstone	500
Squared stonework	250
Rubble, laid in lime mortar	80
Rubble, laid in cement mortar	150
Concrete, 1 Portland, 2 sand, 5 broken stone	150

Foundation Soils.	Tons per Sq. Ft.
Rock, hardest in native bed	100
Equal to best ashlar masonry	25–40
Equal to best brick	15–20
Clay, dry, in thick beds	4–6
Moderately dry, in thick beds	2–4
Soft	1–2
Gravel and coarse sand, well cemented	8–10
Sand, compact and well cemented	4–6
Clean, dry	2–4
Quicksand, alluvial soils, etc.	.5–1

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BREAKING LOADS FOR ROUND CAST-IRON COLUMNS.

(*In Thousand Pounds.*)

Diam. of Col. In.	Thickness. In.	Length of Column in Feet.						
		8 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
6	½	418						
6	⅝	505	412					
6	¾	570	465	374				
6	⅞	651	525	423	347			
7	½	560	474	393	332	270		
7	⅝	655	566	476	402	332	287	
7	¾	820	658	544	456	384	324	280
7	⅞	880	732	610	510	425	360	313
7	1	971	810	670	559	470	396	339
8	½	850	735	631	542	462	400	352
8	¾	1,000	910	743	640	545	468	405
8	⅞	1,120	960	810	710	620	529	455
8	1	1,260	1,082	930	785	675	578	502
8	1⅛	1,360	1,185	1,005	865	732	625	545
9	⅝	1,040	923	810	710	620	535	480
9	¾	1,220	1,073	950	820	720	628	560
9	⅞	1,360	1,200	1,050	918	805	595	614
9	1	1,550	1,362	1,192	1,039	900	758	682
9	1⅛	1,710	1,500	1,300	1,130	958	851	751
10	¾	1,420	1,280	1,141	1,020	900	798	705
10	⅞	1,640	1,495	1,318	1,170	1,036	910	820
10	1	1,830	1,580	1,460	1,292	1,143	1,010	895
10	1⅛	2,030	1,810	1,470	1,310	1,160	1,110	980
11	¾	1,640	1,510	1,363	1,260	1,120	1,000	895
11	⅞	1,840	1,680	1,540	1,385	1,250	1,113	990
11	1	2,100	1,923	1,740	1,570	1,420	1,258	1,119
11	1⅛	2,300	2,110	1,920	1,720	1,550	1,370	1,217
12	¾	1,869	1,740	1,600	1,440	1,310	1,200	1,080
12	⅞	2,130	1,960	1,800	1,630	1,490	1,360	1,223
12	1	2,380	2,180	2,020	1,840	1,670	1,500	1,360
12	1⅛	2,580	2,350	2,180	1,990	1,800	1,620	1,470
13	¾	2,020	1,900	1,740	1,620	1,480	1,363	1,265
13	⅞	2,400	2,250	2,100	1,920	1,760	1,590	1,465
13	1	2,660	2,480	2,320	2,120	1,940	1,745	1,610
13	1⅛	2,920	2,720	2,540	2,310	2,120	1,900	1,750
14	⅞	2,600	2,450	2,310	2,160	1,970	1,820	1,670
14	1	2,930	2,700	2,580	2,390	2,140	2,090	1,880
14	1⅛	3,250	3,090	2,850	2,670	2,440	2,300	2,070
14	1¼	3,560	3,360	3,140	2,910	2,660	2,440	2,250

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SAFE UNIFORMLY DISTRIBUTED LOADS FOR RECTANGULAR WOODEN BEAMS 1 INCH THICK.

Span in Feet.	Depth of Beam.							
	6″	7″	8″	9″	10″	12″	14″	16″
5	800	1,090	1,420	1,800	2,220	3,200	4,380	5,690
6	665	910	1,190	1,500	1,850	2,670	3,650	4,740
7	570	780	1,020	1,290	1,590	2,290	3,130	4,060
8	500	680	890	1,130	1,390	2,000	2,740	3,560
9	445	610	790	1,000	1,230	1,780	2,430	3,160
10	400	540	710	900	1,110	1,600	2,190	2,840
11	365	495	650	820	1,010	1,450	1,990	2,590
12	335	450	590	750	930	1,330	1,820	2,370
13	310	420	550	690	860	1,230	1,690	2,200
14	285	390	510	640	800	1,150	1,570	2,040
15	265	360	480	600	740	1,070	1,460	1,900
16	250	340	450	560	700	1,000	1,370	1,780
17	235	320	420	530	650	940	1,290	1,680
18	220	300	400	500	620	890	1,220	1,590
19	210	290	380	480	590	840	1,150	1,500
20	200	272	360	450	560	800	1,090	1,420
21	190	260	340	430	530	760	1,040	1,360
22	180	248	325	410	510	730	1,000	1,300
23	175	237	310	390	480	700	950	1,240
24	165	228	297	380	460	670	910	1,190
25	160	218	285	360	450	640	880	1,140
26	155	210	275	350	430	620	840	1,100
27	149	202	265	330	410	590	810	1,060
28	143	195	255	315	400	570	780	1,020
29	138	188	246	307	380	550	750	980
30	134	182	237	297	370	530	730	950

Safe load for any thickness = safe load for 1 in. × thickness in inches.

Thickness for any load = load ÷ safe load for 1 in.

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MATERIALS OF CONSTRUCTION.

STONE.

Granite is the most valuable stone where strength is required, its crushing strength averaging about 20,000 lb. per sq. in. Exposed to fire, it disintegrates at a temperature of from 900° to 1,000° F., being less durable in this respect than fine-grained, compact sandstones. The average weight of granite is about 167 lb. per cu. ft.

Limestone is a very common building stone, and, when compact, is very durable. It is usually quite absorptive, and becomes dirty quickly; while under intense heat, it is converted into lime. Limestone must be well seasoned before use, to get rid of the quarry water. The strength of limestone varies from 7,000 to 25,000 lb. per sq. in., the average being about 15,000 lb. The weight of limestone is about 155 to 160 lb. per cu. ft.

Sandstone is, in general, an excellent building stone, capable of resisting great heat, and the better kinds absorb only small quantities of water. The dark-brown, flinty sandstones retain their color very well, ranking better than granite. A stone containing much pyrites becomes unevenly discolored, due to formation of rust, and, hence, the stone should be carefully examined in this respect. The average strength of sandstones is about 11,000 lb. per sq. in., varying from 4,000 to 17,000 lb. The weight of sandstone is about 140 lb. per cu. ft.

When a good stone is tapped with a hammer, it gives out a ringing sound. The absorptive quality of a stone may be tested by noting the increase in weight after soaking in water for 24 hours. One that increases 5 per cent. or more should not be used.

BRICK.

If two good bricks are struck together, they give out a ringing sound; while if the sound is dull, the brick is of inferior quality. A good brick will not absorb more than 10 per cent. of its weight of water; the best will not absorb over 5 per cent., while soft brick will take up from 25 to 35 per cent.

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SIZE OF BRICK.

Name.	Thickness. Inches.	Width. Inches.	Length. Inches.
Common brick	2-2¼	4	8¼
Philadelphia pressed	2¼	4	8 3/16
Peerless Brick Co.	2⅛	4⅛	8⅛
Baltimore and Trenton	2⅛	4⅛	8¼
Croton	2¼	4	8⅛
Colabaugh	2⅛	3⅞	8¼
Maine common	2⅛	3⅛	7⅛
North River common	2¼	3⅛	8
Milwaukee	2⅛	4⅛	8⅛
Stourbridge firebrick	2⅛	4⅛	9⅛

TERRA COTTA.

Solid terra cotta weighs about 120 lb. per cu. ft., while hollow pieces of ordinary size average from 65 to 85 lb. The safe working strength of terra-cotta blocks in walls is about 5 tons per sq. ft., if unfilled, and 10 tons, if filled solid with concrete.

LIME.

Lime weighs about 66 lb. per bu., or about 53 lb. per cu. ft. One barrel of lime, weighing 230 lb., will make about 2½ bbl., or .3 cu. yd., of stiff paste. In 1-to-3 mortar, 1 bbl. of unslaked lime will make about 6¾ bbl. of mortar; or 1 bbl. of lime paste will make about 3 bbl. of mortar. For a 1-to-2 mortar, about 1 bbl. of quicklime to 5 or 5½ bbl. of sand are used.

CEMENTS.

The two kinds of hydraulic cements are termed Portland and natural (often called Rosendale, from a place in New York where much of it is made).

Portland cements are dark in color, weigh from 90 to 100 lb. per cu. ft., are very slow in setting, and attain great ultimate strength. Natural cements are light in color, weigh from 50 to 60 lb. per cu. ft., are very quick setting, and become from ⅛ to ¼ as strong as Portland cement.

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A barrel of Portland cement weighs about 375 lb. net; one of the Eastern Rosendales, 300 lb., and Western Rosendales (from Wisconsin, Kentucky, Illinois, etc.), about 265 lb. A cubic foot of slightly compacted cement mixed with ½ cu. ft. of water will make from ⅔ to ¾ cu. ft. of paste; or 1 bbl. of cement will make about 3¾ cu. ft. of stiff paste.

CONCRETE.

A very good concrete may be made by using the following quantities of materials, which, when mixed, will make 1 cu. yd.: 2 bbl. of Rosendale cement, ½ cu. yd. of sand, and $\frac{9}{10}$ cu. yd. of broken stone.

The strength of concrete increases considerably with age. For example, a Portland-cement concrete, 1 month old, will crush under a load of about 15 tons per sq. ft., while if it is a year old, it will sustain about 100 tons per sq. ft. Natural-cement concretes, of ages from 6 months to 4 years, showed crushing strengths of from 70 to 100 tons per sq. ft.

THICKNESS OF WALLS.

The thickness of foundation walls in all the large cities is controlled by the building laws. Where there are no existing laws, the following table will serve as a guide:

THICKNESS OF FOUNDATION WALLS.

Height of Building.	Dwellings, Hotels, etc.		Warehouses.	
	Brick. Inches.	Stone. Inches.	Brick. Inches.	Stone. Inches.
Two stories	12 or 16	20	16	20
Three stories	16	20	20	24
Four stories	20	24	24	28
Five stories	24	28	24	28
Six stories	24	28	28	32

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TIN ROOFING.

There are two kinds of tin-roof coverings in common use, namely, *flat seam* and *standing seam*. In the former method, the sheets of tin are locked into one another at the edges, and nailed to the roof-boards, as shown in Fig. 1. Six or eight 1″ wire nails are allowed to the ordinary sheet. The seams are flattened with wooden mallets and soldered water-tight. The seams constitute the weakest part of a flat tin roof, and should therefore be made and soldered with great care. The tinner should not hurry the soldering, for time is required to properly "sweat" the solder into the seams. Resin is the best flux; chloride of zinc or other acids should not be used, because in a short time they will corrode the tin so badly at the seams as to cause them to leak. A better method of fastening the sheets to the roof is by means of tin cleats about 1½ in. × 4 in. These are nailed to the roof, and locked over the upper edge of the sheet, about 15 in. apart.

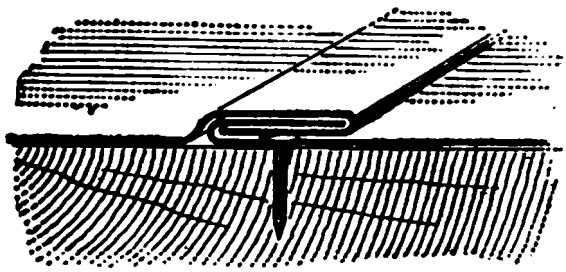

FIG. 1.

Standing-seam roofing is that in which the sloping seams are composed of two upstands interlocked, and held in place by cleats. They are not soldered, but are simply locked together, as shown in Fig. 2. The sheets of tin are first double-seamed and soldered together into long strips that reach from eaves to ridge. One edge is turned up about 1¼ in. and the other about 1½ in. The cleats are placed about 15 or 18 in. apart. When the upstands and cleats are locked together the standing seam is about 1 in. high. Only the best quality of tin should be used, and it should be painted on the under side before it is laid. Waterproof roofing felt should be laid under the tin.

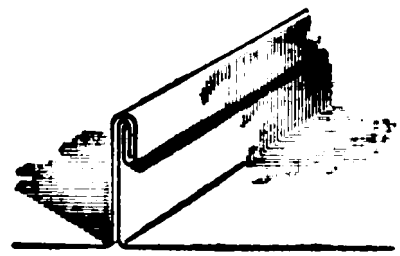

FIG. 2.

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HEATING AND VENTILATION.

HEAT.

MEASUREMENTS OF HEAT.

Definitions.—*Heat* is commonly defined as a form of energy due to a rapid vibratory motion of the molecules of which the heated substance is composed, the higher the heat the greater being the rapidity of molecular movement.

Sensible heat is that measurable portion of the heat imparted to a body that serves to raise its *temperature*, the latter term being used to indicate the intensity of heat or cold.

Instruments that measure the intensity of heat are called *thermometers* or *pyrometers*. The quantity of heat developed by the combustion of fuel, or taken up or given off by the gases or vapors in passing from the gaseous to the liquid condition, is measured by instruments called *calorimeters*.

The unit quantity of heat is the quantity required to raise the temperature of 1 lb. of water from 62° to 63°; this unit is called the *British thermal unit*, abbreviated to B. T. U.

Latent Heat.—The heat expended in changing a body from the solid to the liquid state, or from the liquid to the gaseous state, without change of temperature, is called its *latent heat*.

The temperature at which a body changes from a solid to a liquid state is called its *temperature of fusion;* and the number of B. T. U. required to effect this change in a body weighing 1 lb. is called its *latent heat of fusion*. The temperature at which a body changes from a liquid state to a vapor (gas) is called its *temperature of vaporization;* and the heat required to effect this change in 1 lb. of the liquid is called its *latent heat of vaporization*.

When a vapor changes back to a liquid, it is said to *condense;* and when a liquid changes back to a solid, it is said to *freeze;* in either case, an amount of heat, equal to the latent heat of vaporization or of fusion, as the case may be, must be abstracted from (given up by) the body before the change can be effected.

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The following table shows the latent heat of fusion and vaporization for 1 lb. of various substances, they having first been raised to the temperature at which the change takes place, and the pressure being one atmosphere, or 14.7 lb. per sq. in.:

TEMPERATURES AND LATENT HEATS OF FUSION AND OF VAPORIZATION.

Substance.	Temperature of Fusion.	Temperature of Vaporization.	Latent Heat of Fusion.	Latent Heat of Vaporization.
Water	32°	212°	142.65	966.6
Mercury	—37.8°	662°	5.09	157
Sulphur	228.3°	824°	13.26	
Tin	446°		25.65	
Lead	626°		9.67	
Zinc	680°	1,900°	50.63	493
Alcohol	—148°	173°		372
Oil of turpentine	14°	313°		124
Linseed oil		600°		
Aluminum	1,400°			
Copper	2,100°			
Cast iron	2,192°	3,300°		
Wrought iron	2,912°	5,000°		
Steel	2,520°			
Platinum	3,632°			

The temperature of vaporization in the above table is the boiling point of the liquid under the ordinary atmospheric pressure of 14.7 lb. per sq. in.

Specific Heat.—The *specific heat* of a body is the ratio between the quantity of heat required to warm that body 1° and the quantity of heat required to warm an equal weight of water 1°.

Rule.—*To find the number of B. T. U. required to raise the temperature of a body a given number of degrees, multiply the specific heat of the body by its weight, in pounds, and by the number of degrees.*

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Denote the number of B. T. U. required by U; the specific heat by c; the weight by W; and let t and t_1 be the temperatures before and after the heat is applied, respectively.

Then, $$U = c\,W\,(t_1 - t).$$

The specific heat of various substances is shown by the following table:

SPECIFIC HEATS.

SOLIDS.

Copper	.0951	Cast iron	.1298
Wrought iron	.1138	Lead	.0314
Steel (soft)	.1165	Silver	.0570
Steel (hard)	.1175	Tin	.0562
Zinc	.0956	Ice	.5040
Brass	.0939	Sulphur	.2026
Glass	.1937	Charcoal	.2410

LIQUIDS.

Water	1.0000	Lead (melted)	.0402
Alcohol	.7000	Sulphur (melted)	.2340
Mercury	.0333	Tin (melted)	.0637
Benzine	.4500	Sulphuric acid	.3350
Glycerine	.5550	Oil of turpentine	.4260

GASES.

Air	.23751	Superheated steam	.4805
Oxygen	.21751	Carbonic oxide (CO)	.2479
Nitrogen	.24380	Carbonic acid (CO_2)	.2170
Hydrogen	3.40900	Olefiant gas	.4040

The table shows that the amount of heat that would be required to raise the temperature of 1 lb. of water would be sufficient to heat, to an equal degree, about 8 lb. of cast iron, or 30 lb. of mercury, or 4 lb. of air, which is about 54 cu. ft.

The specific heats for gases given in the above table are true only when the pressure remains constant.

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Thermometers.—There are two fixed points on all thermometers, viz., the freezing and the boiling. On the *Fahrenheit thermometer*, the distance between the two fixed points is divided into 180 equal parts, or degrees. The freezing point is marked 32° and the boiling point 212°; 32 parts are marked off from the freezing point downwards, and the last one is marked 0°, or zero. The graduations are carried above the boiling point and below the zero point as far as desired.

In graduating a *centigrade thermometer*, the freezing point is marked 0°, and the boiling point 100°; the distance between the freezing and boiling points is divided into 100 equal parts; these equal divisions are carried as far below the freezing point and above the boiling point as desired.

In Russia and a few other countries another thermometer is used, called the *Réaumur;* the freezing point is marked 0°, or zero, and the boiling point 80°, the space between these two points being divided into 80 equal parts.

The abbreviations for these scales are: Fahrenheit, F.; centigrade, C; and Réaumur, R. The reading on one scale may be converted into a corresponding reading on either of the other scales by the following formula:

$$\text{Fahrenheit} = \frac{9}{5}\,\text{C} + 32 \quad = \frac{9}{4}\,\text{R} + 32$$

$$\text{Centigrade} = \frac{5}{9}\,(\text{F} - 32) = \frac{5}{4}\,\text{R}$$

$$\text{Réaumur} = \frac{4}{9}\,(\text{F} - 32) = \frac{4}{5}\,\text{C}$$

Absolute Zero.—It has been found by experiment that all perfect gases will expand $\frac{1}{480}$ of their volume when heated from zero to 1° above it. It is inferred, therefore, that the ultimate limit of contraction will be found at 460° below zero on the Fahrenheit scale, and that at this point all motion of the molecules ceases. This point is called the *absolute zero*, and temperatures measured therefrom are called *absolute temperatures.*

The temperature that is indicated by the thermometer may be converted into absolute temperature by adding it to 460°. Thus, a temperature of 85° by the thermometer

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corresponds to the absolute temperature of 85 + 460 = 545°. On the centigrade scale the absolute zero is 273½° below the zero point. On the Réaumur scale it is 219° below zero. When the thermometer indicates temperatures below the zero point of its graduation, the indicated temperature must be subtracted from 460, 273½, or 219, respectively, to find the absolute temperature.

TRANSMISSION OF HEAT.

Heat is transmitted by radiation, by conduction, and by convection.

The term *radiation* is commonly used to signify the transmission of heat through space unoccupied by tangible forms of matter, or through matter unaffected by such transmission of heat. For example, heat may be transmitted, by radiation, through ice without causing it to melt, none of the heat being absorbed until it reaches some heat-absorbing surface.

When the transmission of heat through any substance takes place without causing appreciable motion; i. e., circulation of the affected particles of the heated body, the manner of transmission is called *conduction*, which term, as a rule, is applied to the transmission of heat through solids.

The diffusion of heat through a liquid or gas by motion, or circulation, of its constituent particles is termed *convection*. Convection currents caused by the application of heat at the bottom of a vessel containing a liquid, such as water, are due to the expansion and consequent decrease in density of the lower particles which become lighter when heated and ascend because of their buoyancy, the rising particles being replaced by descending currents of colder particles. If the heat is applied to the surface of the liquid, little convection will occur; being confined to the upper portion of the liquid, the heat will be conducted downwards through the liquid, without motion, in the same manner as though the liquid were a solid substance. The diffusion of heat throughout a liquid may be greatly facilitated by convection if the heat is applied to the lower part of the mass. When in motion each heated particle comes into successive conta-

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with a great number of colder particles, to which its heat is conducted by actual contact. Air and other gases must be heated mainly by convection.

The transmission of heat through a body may be divided into three phases: (1) the absorption of the heat at the receiving surface; (2) the conduction through the substance of the body; (3) the emission from the radiating surface.

All metals conduct heat much faster than they can either absorb it at, or emit it from, their surfaces, and hence a knowledge of their actual conducting power is not so valuable or essential in the arts of heating and ventilation as a knowledge of their transmitting power.

EXPANSION OF BODIES BY HEAT.

If a body absorbs heat, its volume will be changed correspondingly. Nearly all bodies expand when heated; a few substances, however, contract, but these exceptions are of no practical importance.

Air and all other gases expand uniformly for each degree of rise in temperature above zero. Air, at zero F., will expand $\frac{1}{480}$ of its volume for each degree of rise in temperature. Thus, air at 70° will have a volume equal to $1 + \frac{70}{480}$, or $\frac{550}{480}$ of its volume at zero, if its tension remains unchanged. By tension is meant the pressure that a gas exerts on the vessel that confines it.

If metallic bodies are heated above a certain temperature, varying for different metals, and the heat is continued for any considerable length of time, the metal will become permanently elongated, and upon cooling will not contract to its original dimensions. The metal is then said to be *swelled*. Thus, grate bars in a furnace, or pipes which are exposed to intense heat, will increase considerably in length during long use. The strength of the material deteriorates at the same time. Thus, plates or other parts of furnaces which are unduly heated will swell permanently, and bulge or crack the adjoining parts.

The linear expansion, or extension, of metals for 1° rise of temperature is given in the following table:

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COEFFICIENT OF EXPANSION FOR A NUMBER OF SUBSTANCES.

Name of Substance.	Linear Expansion.	Surface Expansion.	Cubic Expansion.
Cast iron	.00000617	.00001234	.00001850
Copper	.00000955	.00001910	.00002864
Brass	.00001037	.00002074	.00003112
Silver	.00000690	.00001390	.00002070
Bar iron	.00000686	.00001372	.00002058
Steel (untempered)	.00000599	.00001198	.00001798
Steel (tempered)	.00000702	.00001404	.00002106
Zinc	.00001634	.00003268	.00004903
Tin	.00001410	.00002820	.00003229
Mercury	.00003334	.00006668	.00010010
Alcohol	.00019259	.00038518	.00057778
Gases			.00203252

EXAMPLE.—A wrought-iron bar 22 ft. long is heated from 70° to 300°. How much will it lengthen?

SOLUTION.— $22 \times (300 - 70) \times .00000686 = .0347116$ ft. = .41654 in.

AIR.

HEAT CONTAINED IN AIR.

If a current of hot air, of a given volume of flow per minute, is cooled, the quantity of heat given off in the process may be computed by the following rule:

Rule.—*Multiply together the given volume of the air, the number of degrees through which it is cooled, and the amount of heat contained in 1 cu. ft. of air at the original temperature, as shown in the accompanying table. If this product be divided by the original temperature, the quotient will be the amount of heat given off, in heat units.*

EXAMPLE.—A current of hot air having a temperature of 150° and a volume of 400 cu. ft. per min. is cooled, in passing through a room, to 65°; what amount of heat is given off per minute?

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SOLUTION.—From the table, the heat contained in 1 cu. ft. at 150° is 2.3196 B. T. U. Applying the rule just given,

$$\frac{400 \times (150 - 65) \times 2.3196}{150} = 525.78 \text{ B. T. U.} \quad \text{Ans.}$$

PROPERTIES OF AIR AT PRESSURE OF 14.7 LB. PER SQ. IN.

Temperature. F.	Weight per Cubic Foot. Lb.	B. T. U. Given Up by 1 Cu. Ft. of Air in Cooling to 0°.	Temperature. F.	Weight per Cubic Foot. Lb.	B. T. U. Given Up by 1 Cu. Ft. of Air in Cooling to 0°.
0	.08635	.0000	75	.07424	1.3225
2	.08597	.0408	80	.07355	1.3975
4	.08560	.0813	85	.07288	1.4713
6	.08523	.1214	90	.07222	1.5438
8	.08487	.1613	95	.07157	1.6149
10	.08451	.2007	100	.07093	1.6847
12	.08415	.2398	110	.06968	1.8205
14	.08380	.2786	120	.06848	1.9518
16	.08344	.3171	130	.06732	2.0786
18	.08309	.3552	140	.06620	2.2013
20	.08275	.3931	150	.06511	2.3196
24	.08206	.4678	160	.06406	2.4344
28	.08139	.5413	170	.06305	2.5458
32	.08073	.6136	180	.06206	2.6532
36	.08008	.6847	190	.06111	2.7577
40	.07944	.7547	200	.06018	2.8587
45	.07865	.8406	210	.05929	2.9572
50	.07788	.9249	220	.05841	3.0521
55	.07712	1.0074	230	.05756	3.1444
60	.07638	1.0885	240	.05674	3.2343
65	.07566	1.1681	250	.05594	3.3216
70	.07494	1.2459	260	.05517	3.4069

EXAMPLE.—How much heat will be required to warm 400 cu. ft. of air to a temperature of 150°, the temperature out-of-doors being 10°?

SOLUTION.—The weight of 1 cu. ft. at 10° is .08451 lb. Hence, the number of B. T. U. required to heat 400 cu. ft. from 10° to 150° is

$$U = .23751 \times .08451\ (150 - 10) \times 400 = 1{,}124 \text{ B. T. U.} \quad \text{Ans.}$$

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VOLUME AND WEIGHT OF AIR.

The volume of air and its weight per cubic foot change with the temperature. The final volume may be computed by the following:

Rule.—*Reduce both the original and final temperatures to absolute temperatures. Multiply the original volume by the final absolute temperature and divide by the original absolute temperature. The quotient will be the final volume.*

Or, let V = original volume;
V_1 = final volume;
T = original absolute temperature,
T_1 = final absolute temperature;

$$V_1 = \frac{V\,T_1}{T}.$$

Example.—What will be the volume of 400 cu. ft. of air, having a temperature of 150°, when it is cooled to 10°?

Solution.—Applying the above rule,

$$V_1 = \frac{400\,(460 + 10)}{460 + 150} = 308.19 \text{ cu. ft.} \quad \text{Ans.}$$

The final weight of a given volume of air may be computed from the following:

Rule.—*Multiply the original weight by the original absolute temperature, and divide the product by the final absolute temperature. The quotient will be the final weight.*

Or, letting W = original weight;
W_1 = final weight;

$$W_1 = \frac{W\,T}{T_1}.$$

Example.—A chimney of 1 sq. ft. area and 120 ft. high is filled with hot air at a temperature of 450°; the temperature of the atmosphere is 60°; what is the difference in the weight of the air before and after it is heated?

Solution.—The volume of the air is 120 cu. ft. The original weight is (see preceding table) $120 \times .07638 = 9.1656$ lb., and the absolute temperature is $60 + 460 = 520°$. Then, applying the last rule,

$$W_1 = \frac{9.1656 \times 520}{460 + 450} = 5.2375 \text{ lb.}$$

The change in weight $= 9.1656 - 5.2375 = 3.9281$ lb. Ans.

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VOLUME, DENSITY, AND PRESSURE OF AIR.

(*D. K. Clark.*)

Degrees F.	Volume at Atmospheric Pressure		Density, lb. per cu. ft. at Atmospheric Pressure	Pressure at Constant Volume	
	Cubic Feet in 1 lb.	Comparative Volume		Pounds per Sq. In.	Comparative Pressure
0	11.583	.881	.086331	12.96	.881
32	12.387	.943	.080728	13.86	.943
40	12.586	.958	.079439	14.08	.958
50	12.840	.977	.077884	14.36	.977
62	13.141	1.000	.076097	14.70	1.000
70	13.342	1.015	.074950	14.92	1.015
80	13.593	1.034	.073565	15.21	1.034
90	13.845	1.054	.072230	15.49	1.054
100	14.096	1.073	.070942	15.77	1.073
110	14.344	1.092	.069721	16.05	1.092
120	14.592	1.111	.068500	16.33	1.111
130	14.846	1.130	.067361	16.61	1.130
140	15.100	1.149	.066221	16.89	1.149
150	15.351	1.168	.065155	17.19	1.168
160	15.603	1.187	.064088	17.50	1.187
170	15.854	1.206	.063089	17.76	1.206
180	16.106	1.226	.062090	18.02	1.226
200	16.606	1.264	.060210	18.58	1.264
210	16.860	1.283	.059313	18.86	1.283
212	16.910	1.287	.059135	18.92	1.287
220	17.111	1.302	.058442	19.14	1.302

STEAM

DEFINITIONS.

The process of changing water (or other liquids) into vapor by means of heat is called *evaporation* or *vaporization.*

When steam is in contact with the water from which it is generated it is called *saturated steam.*

Steam, if not in contact with water, may be heated like air or any other gas until its temperature is higher than the boiling point. Steam in this condition is said to be *superheated.* The specific heat of superheated steam is .4805, or, say, .48 for ordinary purposes.

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STEAM TABLES.

Whenever the pressure of saturated steam is changed, there are other properties that change with it. These properties are the following:

1. The temperature of the steam, or, what is the same thing, the boiling point.

2. The number of B. T. U. required to raise a pound of water from 32° (freezing) to the boiling point corresponding to the given pressure. This is called the *heat of the liquid.*

3. The number of B. T. U. required to change the water at the boiling temperature into steam at the same temperature. This is called the *latent heat of vaporization*, or, simply, the *latent heat.*

4. The number of heat units required to change a pound of water at 32° to steam of the required temperature and pressure. This is called the *total heat of vaporization*, or, simply, the *total heat.*

It is plain that the *total heat* is the sum of the *heat of the liquid* and the *latent heat.* That is, total heat = heat of liquid + latent heat.

5. The *specific volume* of the steam at the given pressure; that is, the number of cubic feet occupied by a pound of steam of the given pressure.

6. The *density* of the steam; that is, the weight of 1 cubic foot of the steam at the given pressure.

All the above properties are different for different pressures. For example, if steam boils under atmospheric pressure, the temperature is 212°; the heat of the liquid is 180.531 B. T. U.; the latent heat, 966.069 B. T. U.; the total heat, 1,146.6 B. T. U. A pound of steam at this pressure occupies 26.37 cu. ft., and a cubic foot of the steam weighs about .037928 lb. When the pressure is 70 lb. per sq. in. above vacuum, the temperature is 302.774°; the heat of the liquid is 272.657 B. T. U.; the latent heat is 901.629 B. T. U.; the total heat is 1,174.286 B. T. U. A pound of the steam occupies 6.076 cu. ft., and a cubic foot of the steam weighs .164584 lb.

These properties have been determined by direct experiment for all ordinary steam pressures. They are given in the table of the properties of saturated steam.

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EXPLANATION OF THE TABLE.

Column 1 gives the pressures from 1 to 300 lb. These pressures are above vacuum. The steam gauges fitted on steam boilers register the pressure above the atmosphere. That is, if the steam is at atmospheric pressure, 14.7 lb. per sq. in., the gauge registers 0. Consequently, the atmospheric pressure must be added to the reading of the gauge to obtain the pressure above vacuum. In using the table, care must be taken *not* to use the gauge pressures without first adding 14.7 lb. per sq. in.

Pressures registered above vacuum are called *absolute pressures.* The pressures given in column 1 are *absolute.* Absolute pressure per square inch = gauge pressure per square inch + 14.7.

Column 2 gives the temperature of the steam when at the pressure shown in column 1.

Column 3 gives the *heat of the liquid.* It will be noticed that the values in column 3 may be obtained approximately by subtracting 32° from the temperature in column 2. If the specific heat of water were exactly 1.00, it would, of course, take exactly 212 − 32 = 180 B. T. U. to raise a pound of water from 32° to 212°. But experiment shows that the specific heat of water is slightly greater than 1.00 when the temperature of the water is above 62°, and it therefore takes 180.531 B. T. U. to raise a pound of water from 32° to 212°.

Column 4 gives the *latent heat of vaporization,* which is seen to decrease slightly as the pressure increases.

Column 5 gives the *total heat of vaporization.* The values in column 5 may be obtained by adding together the corresponding values in columns 3 and 4.

Column 6 gives the weight of a cubic foot of steam in pounds. As would be expected, the steam becomes denser as the pressure rises, and weighs more per cubic foot.

Column 7 gives the number of cubic feet occupied by 1 pound of steam at the given pressure. It will be noticed that the corresponding values of columns 6 and 7 multiplied together always produce 1. Thus, for 31.3 pounds pressure, gauge, .11088 × 9.018 = 1.000, nearly.

Column 8 gives the ratio of the volume of a pound of

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steam at the given pressure, and the volume of a pound of water at 39.2°. The values in column 8 may be obtained by dividing 62.425, the weight of a cubic foot of water at 39.2°, by the numbers in column 6.

Examples on the Use of the Steam Table.

Example 1.—Calculate the heat required to change 5 lb. of water at 32° into steam at 92 lb. pressure above vacuum.

Solution.—From column 5, the total heat of 1 lb. at 92 lb. pressure is 1,180.045 B. T. U.

$$1{,}180.045 \times 5 = 5{,}900.225 \text{ B. T. U.}$$

Example 2.—How many heat units are required to raise 8½ lb. of water from 32° to 250° F.?

Solution.—Looking in column 3, the heat of the liquid of 1 lb. at 250.293° is 219.261 B. T. U. $219.261 - .293 = 218.968$ B. T. U. = heat of liquid for 250°. Then, for 8½ lb. it is $218.968 \times 8\frac{1}{2} = 1{,}861.228$ B. T. U.

Example 3.—How many foot-pounds of work will it require to change 60 lb. of boiling water at 80 lb. pressure, absolute, into steam of the same pressure?

Solution.—Looking under column 4, the latent heat of vaporization is 895.108; that is, it takes 895.108 B. T. U. to change 1 lb. of water at 80 lb. pressure into steam of the same pressure. Therefore, it takes $895.108 \times 60 = 53{,}706.48$ B. T. U. to perform the same operation on 60 lb. of water.

$$53{,}706.48 \times 778 = 41{,}783{,}641.44 \text{ ft.-lb.}$$

Example 4.—Find the volume occupied by 14 lb. of steam at 30 lb., *gauge* pressure.

Solution.— 30 lb., gauge pressure $= 30 + 14.7 = 44.7$, absolute pressure. The nearest pressure in the table is 44 lb., and the volume of a pound of steam at that pressure is 9.403 cu. ft. The volume of a pound at 46 lb. pressure is 9.018 cu. ft. $9.403 - 9.018 = .385$ cu. ft., the difference in volume for a difference in pressure of 2 lb. $\frac{.385}{2} = .1925$ cu. ft., the difference in volume for a difference in pressure of 1 lb. $.1925 \times .7 = .135$ cu. ft., the difference in volume for a difference in pressure of .7 lb. Therefore, $9.403 - .135 = 9.268$ cu. ft. is the volume of 1 lb. of steam at 44.7 lb. pressure. The .135 cu. ft.

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is subtracted from 9.403 cu. ft., since the volume is less for a pressure of 44.7 lb. than for a pressure of 44 lb.

$$9.268 \times 14 = 129.752 \text{ cu. ft.}$$

EXAMPLE 5.—Find the weight of 40 cu. ft. of steam at a temperature of 254° F.

SOLUTION.—The weight of 1 cu. ft. of steam at 254.002°, from the table, is .078839 lb. Neglecting the .002°, the weight of 40 cu. ft. is, therefore,

$$.078839 \times 40 = 3.15356 \text{ lb.}$$

EXAMPLE 6.—How many pounds of steam at 64 lb. pressure, absolute, are required to raise the temperature of 300 lb. of water from 40° to 130° F., the water and steam being mixed?

SOLUTION.—The number of heat units required to raise 1 lb. from 40° to 130° is $130 - 40 = 90$ B. T. U. (Actually a little more than 90 would be required, but the above is near enough for all practical purposes.) Then, to raise 300 lb. from 40° to 130° requires $90 \times 300 = 27{,}000$ B. T. U. This quantity of heat must necessarily come from the steam. Now, 1 lb. of steam at 64 lb. pressure gives up, in condensing, its latent heat of vaporization, or 905.9 B. T. U. But, in addition to its latent heat, each pound of steam on condensing must give up an additional amount of heat in falling to 130°. Since the original temperature of the steam was 296.805° F. (see table), each pound gives up by its fall of temperature $296.805 - 130 = 166.805$ B. T. U. Therefore, each pound of the steam gives up a total of

$$905.9 + 166.805 = 1{,}072.705 \text{ B. T. U.}$$

It will, therefore, take $\frac{27{,}000}{1{,}072.705} = 25.17$ lb. of steam to accomplish the desired result.

With the steam tables a reliable thermometer may be used for ascertaining the pressure of saturated steam or for testing the accuracy of a steam gauge. The temperature of the steam being measured by the thermometer, the corresponding absolute pressure is found from the steam tables; the gauge pressure is then found by subtracting 14.7 from the absolute pressure. Thus, the temperature of the steam in a condenser being 142°, we find from the steam tables that the corresponding absolute pressure is 3 lb. per sq. in., nearly.

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THE PROPERTIES OF SATURATED STEAM.

Pressure Above Vacuum in Pounds per Square Inch.	Temperature, Fahrenheit Degrees.	Quantity of Heat in British Thermal Units.			Weight of a Cubic Foot of Steam in Pounds.	Volume of a Pound of Steam in Cubic Feet.	Ratio of Vol. of Steam to Vol. of Equal Weight of Dist. Water at Temp. of Maximum Density.
		Required to Raise Temperature of the Water From 32° to $t°$.	Total Latent Heat at Pressure p.	Total Heat Above 32°.			
1	2	3	4	5	6	7	8
p	t	q	L	H	W	V	R
1	102.018	70.040	1,043.015	1,113.055	.003027	330.4	20,623
2	126.302	94.368	1,026.094	1,120.462	.005818	171.9	10,730
3	141.654	109.764	1,015.380	1,125.144	.008522	117.3	7,325
4	153.122	121.271	1,007.370	1,128.641	.011172	89.51	5,588
5	162.370	130.563	1,000.899	1,131.462	.013781	72.56	4,530
6	170.173	138.401	995.441	1,133.842	.016357	61.14	3,816
7	176.945	145.213	990.695	1,135.908	.018908	52.89	3,302
8	182.952	151.255	986.485	1,137.740	.021436	46.65	2,912
9	188.357	156.699	982.690	1,139.389	.023944	41.77	2,607
10	193.284	161.660	979.232	1,140.892	.026437	37.83	2,361
11	197.814	166.225	976.050	1,142.275	.028911	34.59	2,159
12	202.012	170.457	973.098	1,143.555	.031376	31.87	1,990
13	205.929	174.402	970.346	1,144.748	.033828	29.56	1,845
14	209.604	178.112	967.757	1,145.869	.036265	27.58	1,721
14.69	212.000	180.531	966.069	1,146.600	.037928	26.37	1,646
15	213.067	181.608	965.318	1,146.926	.038688	25.85	1,614
16	216.347	184.919	963.007	1,147.926	.041109	24.33	1,519
17	219.452	188.056	960.818	1,148.874	.043519	22.98	1,434
18	222.424	191.058	958.721	1,149.779	.045920	21.78	1,359
19	225.255	193.918	956.725	1,150.643	.048312	20.70	1,292

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TABLE—(*Continued*).

1	2	3	4	5	6	7	8
p	*t*	*q*	*L*	*H*	*W*	*V*	*R*
20	227.964	196.655	954.814	1,151.469	.050696	19.730	1,231.0
22	233.069	201.817	951.209	1,153.026	.055446	18.040	1,126.0
24	237.803	206.610	947.861	1,154.471	.060171	16.620	1,038.0
26	242.225	211.089	944.730	1,155.819	.064870	15.420	962.3
28	246.376	215.293	941.791	1,157.084	.069545	14.380	897.6
30	250.293	219.261	939.019	1,158.280	.074201	13.480	841.3
32	254.002	223.021	936.389	1,159.410	.078839	12.680	791.8
34	257.523	226.594	933.891	1,160.485	.083461	11.980	948.0
36	260.883	230.001	931.508	1,161.509	.088067	11.360	708.8
38	264.093	233.261	929.227	1,162.488	.092657	10.790	673.7
40	267.168	236.386	927.040	1,163.426	.097231	10.280	642.0
42	270.122	239.389	924.940	1,164.329	.101794	9.826	613.3
44	272.965	242.275	922.919	1,165.194	.106345	9.403	587.0
46	275.704	245.061	920.968	1,166.029	.110884	9.018	563.0
48	278.348	247.752	919.084	1,166.836	.115411	8.665	540.9
50	280.904	250.355	917.260	1,167.615	.119927	8.338	520.5
52	283.381	252.875	915.494	1,168.369	.124433	8.037	501.7
54	285.781	255.321	913.781	1,169.102	.128928	7.756	484.2
56	288.111	257.695	912.118	1,169.813	.133414	7.496	467.9
58	290.374	260.002	910.501	1,170.503	.137892	7.252	452.7
60	292.575	262.248	908.928	1,171.176	.142362	7.024	438.5
62	294.717	264.433	907.396	1,171.829	.146824	6.811	425.2
64	296.805	266.566	905.900	1,172.466	.151277	6.610	412.6
66	298.842	268.644	904.443	1,173.087	.155721	6.422	400.8
68	300.831	270.674	903.020	1,173.694	.160157	6.244	389.8
70	302.774	272.657	901.629	1,174.286	.164584	6.076	379.3
72	304.669	274.597	900.269	1,174.866	.169003	5.917	369.4
74	306.526	276.493	898.938	1,175.431	.173417	5.767	360.0
76	308.344	278.350	897.635	1,175.985	.177825	5.624	351.1
78	310.123	280.170	896.359	1,176.529	.182229	5.488	342.6
80	311.866	281.952	895.108	1,177.060	.186627	5.358	334.5
82	313.576	283.701	893.879	1,177.580	.191017	5.235	326.8
84	315.250	285.414	892.677	1,178.091	.195401	5.118	319.5
86	316.893	287.096	891.496	1,178.592	.199781	5.006	312.5
88	318.510	288.750	890.335	1,179.085	.204155	4.898	305.8

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TABLE—(*Continued*).

1	2	3	4	5	6	7	8
p	*t*	*q*	*L*	*H*	*W*	*V*	*R*
90	320.094	290.373	889.196	1,179.569	.208525	4.796	299.4
92	321.653	291.970	888.075	1,180.045	.212892	4.697	293.2
94	323.183	293.539	886.972	1,180.511	.217253	4.603	287.3
96	324.688	295.083	885.887	1,180.970	.221604	4.513	281.7
98	326.169	296.601	884.821	1,181.422	.225950	4.426	276.3
100	327.625	298.093	883.773	1,181.866	.230293	4.342	271.1
105	331.169	301.731	881.214	1,182.945	.241139	4.147	258.9
110	334.582	305.242	878.744	1,183.986	.251947	3.969	247.8
115	337.874	308.621	876.371	1,184.992	.262732	3.806	237.6
120	341.058	311.885	874.076	1,185.961	.273500	3.656	228.3
125	344.136	315.051	871.848	1,186.899	.284243	3.518	219.6
130	347.121	318.121	869.688	1,187.809	.294961	3.390	211.6
135	350.015	321.105	867.590	1,188.695	.305659	3.272	204.2
140	352.827	324.003	865.552	1,189.555	.316338	3.161	197.3
145	355.562	326.823	863.567	1,190.390	.326998	3.058	190.9
150	358.223	329.566	861.634	1,191.200	.337643	2.962	184.9
160	363.346	334.850	857.912	1,192.762	.358886	2.786	173.9
170	368.226	339.892	854.359	1,194.251	.380071	2.631	164.3
180	372.886	344.708	850.963	1,195.671	.401201	2.493	155.6
190	377.352	349.329	847.703	1,197.032	.422280	2.368	147.8
200	381.636	353.766	844.573	1,198.339	.443310	2.256	140.8
210	385.759	358.041	841.556	1,199.597	.464295	2.154	134.5
220	389.736	362.168	838.642	1,200.810	.485237	2.061	128.7
230	393.575	366.152	835.828	1,201.980	.506139	1.976	123.3
240	397.285	370.008	833.103	1,203.111	.527003	1.898	118.5
250	400.883	373.750	830.459	1,204.209	.547831	1.825	114.0
260	404.370	377.377	827.896	1,205.273	.568626	1.759	109.8
270	407.755	380.905	825.401	1,206.306	.589390	1.697	105.9
280	411.048	384.337	822.973	1,207.310	.610124	1.639	102.3
290	414.250	387.677	820.609	1,208.286	.630829	1.585	99.0
300	417.371	390.933	818.305	1,209.238	.651506	1.535	95.8

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VENTILATION.

GENERAL INFORMATION.

Ventilation is a process of moving foul air from any space and replacing it with fresh air. A positive displacement, however, does not take place; the incoming fresh air chiefly dilutes the foul air to a point suitable for healthful respiration.

Pure air, such as exists in the open country, contains about 4 parts of carbon dioxide, CO_2, per 10,000 parts of air, while badly ventilated rooms often contain as much as 80 parts of CO_2 per 10,000 of air. Hygienists, after careful study, have decided that an increase of 2 parts of CO_2 per 10,000 of air should be accepted as the standard of respirable purity, and any excess of CO_2 above this may be considered as vitiation.

PRODUCTION OF CO_2 PER HOUR.

Source.	Cu. Ft.
Adult man	.6
1 cu. ft. of gas, burning	.8
Ordinary lamp	1.0
Candle	.3

Taking the figures above given—4 parts of CO_2 per 10,000 parts of fresh air, and 6 parts ($= 4 + 2$) per 10,000 of vitiated air—as the standard for proper health conditions, it is found that 3,000 cu. ft. of fresh air per hour is necessary for each adult person. If a different standard than 6 is used, the number of cubic feet per person will be found by dividing 6,000 by the difference between this standard and 4.

If any lights deliver their products of combustion into the room, the amount of CO_2 given off by them should be converted into its equivalent in men, thus: One ordinary gas light equals, in vitiating effect, about 5½ men, an ordinary lamp 1½ men, and an ordinary candle about ½ man.

It is considered good practice to allow 2,000 cu. ft. of fresh air per hour for each inmate of a room or auditorium.

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Hospitals and such places, where the vitiation is due to exhalations from diseased or sick people, should be provided with at least twice this amount.

VOLUME OF AIR NECESSARY TO MAINTAIN A GIVEN STANDARD OF PURITY.

(*American Blower Company.*)

Cubic Feet of Space in Room per Individual.	Proportion of Carbon Dioxide in 10,000 Parts of the Air, not to be Exceeded at End of Hour.						
	6	7	8	9	10	15	20
	Cubic Feet of Air, of Composition 4 Parts of Carbon Dioxide in 10,000, to be Supplied the First Hour.						
100	2,900	1,900	1,400	1,100	900	445	275
200	2,800	1,800	1,300	1,000	800	345	175
300	2,700	1,700	1,200	900	700	245	75
400	2,600	1,600	1,100	800	600	145	None
500	2,500	1,500	1,000	700	500	45	
600	2,400	1,400	900	600	400	None	
700	2,300	1,300	800	500	300		
800	2,200	1,200	700	400	200		
900	2,100	1,100	600	300	100		
1,000	2,000	1,000	500	200	None		
1,500	1,500	500	None	None			
2,000	1,000	None					
2,500	500						

There is a certain minimum space required in buildings for each person, because the carbon dioxide and other exhalations from the body are very slowly diffused through the air. This minimum space, in cubic feet per person, is as follows:

	Cu. Ft.
In a lodging or tenement house	300
In a schoolroom	250
Barracks	600
Ordinary hospital ward	1,000
Fever or surgical ward	1,400

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Floor Space must be considered as much as cubic space. Thus, in a schoolroom, there must be at least 15 sq. ft. of floor surface for each pupil; and in hospitals each bed should have 100 sq. ft. of floor space. In stables, each horse or cow should have 100 sq. ft. of floor space. A horse should have 1,600 cu. ft. of air space, and a cow not less than 1,200. As cows are usually kept to furnish milk for food, it is important that they should be kept in a healthy condition, and that the air around them should be clean.

In quantity, the toxic, or poisonous, organic impurities exhaled from the lungs and surface of the body bear a definite proportion to the amount of carbon dioxide produced by respiration in the same time. The ratio is found to be so nearly constant that, in testing air to determine its fitness for breathing, the percentage of carbon dioxide is taken as an index of the quantity of organic impurities in the air.

Apparatus for testing air, called **carbonometers**, can be purchased from dealers in chemical supplies, the necessary instructions being furnished with the instruments.

NATURAL VENTILATION.

In natural-ventilation systems, the drafts in the flues or ducts are caused by the difference in density between the air in the ducts and the outer atmosphere. The higher the temperature in the ducts, the more rapid will the draft become.

In the following table, 50 per cent. (a fair average in good work) has been deducted from the theoretical flow to offset all ordinary resistances in the flues, such as friction, change in direction, etc. The difference in temperature given in the table is that existing between the outer atmosphere and the average of the air in the flue. Knowing the velocity per minute, and the cubic feet of air per minute to be removed, the area of the flue in square feet is found by dividing the volume by the velocity.

Wind pressure also affects natural ventilation. The movement of air through a building may be accelerated or retarded by the wind, according to the location of the outlets and the kind of cowls used.

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FLOW OF AIR IN FLUES PER SQUARE FOOT OF SECTION, BY NATURAL DRAFT, IN CUBIC FEET PER MINUTE.

Difference in Temp. Deg. F.	Height of Flue in Feet.								
	10	15	20	30	40	50	60	80	100
10	108	133	153	188	217	242	264	306	342
15	133	162	188	230	265	297	325	375	420
20	153	188	217	265	306	342	373	435	485
25	171	210	242	297	342	383	420	485	530
30	188	230	265	325	375	419	461	530	594
40	216	265	305	374	431	482	529	608	680
50	242	297	342	419	484	541	594	680	768
60	266	327	376	460	532	595	650	747	842
70	288	354	407	498	576	644	703	809	910
80	308	379	435	533	616	688	751	866	972
90	326	401	460	565	652	728	795	918	1,029
100	342	419	484	593	684	765	835	965	1,080
125	384	470	541	664	766	857	939	1,085	1,216
150	419	514	593	726	838	937	1,028	1,185	1,325

LOSS OF HEAT FROM BUILDINGS.

ESTIMATING THE HEAT LOSSES.

Heat escapes from buildings in two ways: first, by conduction through the windows, walls, floor, and roof; and second, by ventilation or leakage of warm air. The loss from the latter cause will depend on the tightness of the windows and doors and on the thoroughness of the construction of the walls, especially in wooden buildings. If the outer walls are exposed to the wind, the loss of heat by conduction will be increased from 10 to 30 per cent., while, if they are not wind-tight, the loss by escape of air will be increased to an unknown amount.

The rate at which heat will be lost through walls and windows has been found, by careful experiment, to be

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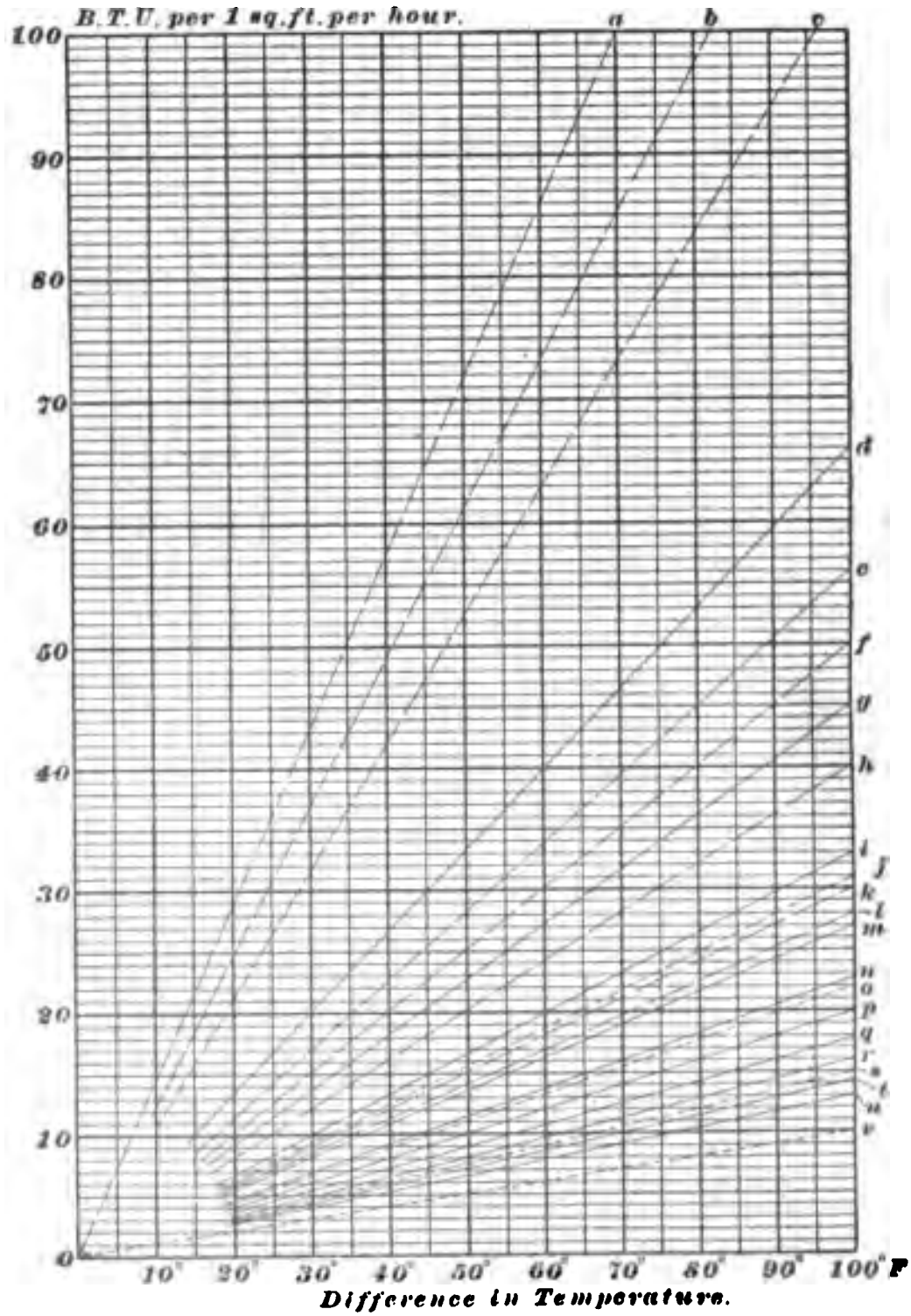

FIG. 1.

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proportional to the difference in temperature between the inside and outside air. The rate of loss under ordinary conditions, in B. T. U., and in rooms that have only a moderate exposure to wind, is shown in a diagram, Fig. 1, by Alfred R. Wolff, M. E. The heat losses under various conditions may be read directly from the diagram, the line *a* showing loss through vault light; *b*, single window; *c*, single skylight; *d*, 4-in. brick wall; *e*, double window; *f*, double skylight; *g*, 8-in. brick wall; *h*, 1-in. pine board door; *i*, 12-in. brick wall; *j*, concrete floor on earth; *k*, fireproof partition; *l*, 2-in. pine board, heavy door; *m*, 16-in. brick wall; *n*, 20-in. brick wall; *o*, concrete floor on brick arch; *p*, 24-in. brick wall; *q*, 28-in. brick wall; *r*, 32-in. brick wall; *s*, wood floor on brick arch; *t*, 36-in. brick wall; *u*, 40-in. brick wall; *v*, double wood floor.

The requisite allowance for different exposures is indicated by the figures on the diagram given in Fig. 2, which shows that for north and west exposures 25 per cent. should normally be added to the calculated heat loss through walls, while for east and south exposures an allowance of 15 and 5 per cent., respectively, should be made. A further allowance of 10 per cent. is made for heating the air that constantly leaks in through cracks and crevices, and a similar allowance is advised for the loss of heat through floors and ceilings. When the rooms are comparatively small, the results given by the use of the diagram in Fig. 1 are increased by the percentage indicated by the figures given inside the circles on the diagram in Fig. 2.

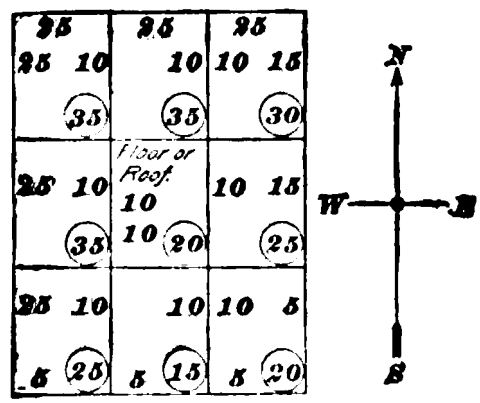

FIG. 2.

If brick walls are made double, with an intervening air space, the loss of heat is less than that of a solid wall having an equal thickness of brick. The saving will be about .07 or .08 B. T. U. per sq. ft.

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The losses shown in the diagram will be increased by circumstances approximately as follows:

Where the exposure is northerly, and the winds are strong. 35 per cent.

When the building is heated during the day and is allowed to cool off somewhat during the night, the exposure being moderate, 10 per cent.

Same, northerly exposure with high winds, 40 per cent.

When the building is heated occasionally, for a day only, and is allowed to freeze for intervals of several days, such as churches and audience rooms. 50 per cent.

The temperature of cellars that are not warmed may be assumed for purposes of calculation to be 32°. Vestibules and corridors, frequently opened to the outer air and not heated, may be assumed to have a temperature of 20°.

HEAT-LOSS COMPENSATION.

In many instances the loss of heat from the room will be partly compensated for by the heat emitted from gas lights, electric lamps, etc., and by the heat given off from the persons occupying the room. The amount of heat from these sources is about as follows:

	B. T. U.
Each adult person	400
Ordinary 5-ft. gas burner, 15 c. p.	4,800
Welsbach incandescent lamp, 50 c. p.	2,000
Electric incandescent lamp, 16 c. p.	220

In lecture halls and large audience rooms, the amount of heat given off by the audience and the lights may equal or exceed that which is lost through the walls and windows. When this occurs, it becomes necessary to lower the temperature of the fresh air supply below the desired temperature of the room during the presence of the audience. Thus, the actual amount of heat required may vary from hour to hour, although the atmospheric temperature is stationary.

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VOLUME AND TEMPERATURE OF HOT-AIR SUPPLY.

The loss of heat per hour by conduction through windows, walls, etc. being given, and also the temperature of the hot-air supply and the desired temperature of the room, the required volume per hour may be computed by the following:

Rule.—*Multiply by 55 the amount of heat lost per hour by conduction and divide the product by the difference between the temperatures of the room and of the hot-air current. The quotient will be the volume of hot air, in cubic feet, required per hour.*

The desired volume of the fresh-air supply, in cubic feet per hour, the amount of heat lost by conduction per hour, and the desired temperature of the rooms being given, the required temperature of the hot air entering the rooms may be computed by the following rule:

Rule.—*Multiply by 55 the amount of heat lost per hour by conduction and divide the product by the volume of the air current. Add the quotient to the desired temperature of the room; the sum will be the required temperature of the hot-air supply.*

FUELS.

KINDS OF FUELS.

Coal is divided into four classes, which are:

1. *Anthracite*, which contains from 92.31 to 100 per cent. of fixed carbon and from 0 to 7.69 per cent. of volatile hydrocarbons.

2. *Semianthracite*, which contains from 87.5 to 92.31 per cent. of fixed carbon and from 7.69 to 12.5 per cent. of volatile hydrocarbons.

3. *Semibituminous coal*, which contains from 75 to 87.5 per cent. of fixed carbon and from 12.5 to 25 per cent. of volatile hydrocarbons.

4. *Bituminous coal*, which contains from 0 to 75 per cent. of fixed carbon and from 25 to 100 per cent. of volatile hydrocarbons.

Anthracite is known to the trade by different names, according to the size into which the lumps are broken.

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These names, and the generally accepted dimensions of the screens over and through which the lumps of coal will pass, are as follows:

Culm passes through $\frac{3}{16}$-in. round mesh.

Rice passes over $\frac{3}{16}$-in. mesh and through $\frac{5}{8}$-in. square mesh.

Buckwheat passes over $\frac{5}{8}$-in. mesh and through $\frac{1}{2}$-in. square mesh.

Pea passes over $\frac{1}{2}$-in. mesh and through $\frac{3}{4}$-in. square mesh.

Chestnut passes over $\frac{3}{4}$-in. mesh and through $1\frac{1}{4}$-in. square mesh.

Stove passes over $1\frac{1}{4}$-in. mesh and through 2-in. square mesh.

Egg passes over 2-in. mesh and through $2\frac{1}{4}$-in. square mesh.

Broken passes over $2\frac{1}{4}$-in. mesh and through $3\frac{1}{4}$-in. square mesh.

Steamboat passes over $3\frac{1}{4}$-in. mesh and out of screen.

Lump passes over bars set from $3\frac{1}{4}$ to 5 in. apart.

Semianthracite coal is broken into the same sizes as anthracite, the sizes having the same name.

Bituminous coal may be broadly divided into three general classes:

1. *Caking Coal.*—This name is given to coals that, when burned in the furnace, swell and fuse together, forming a spongy mass that may cover the whole surface of the grate. These coals are difficult to burn, since the fusing prevents the air passing freely through the bed of burning fuel; when caking coals are burned, the spongy mass must be frequently broken up with the slice bar, in order to admit the air needed for its combustion.

2. *Free-Burning Coal.*—This is often called non-caking coal from the fact that it has no tendency to fuse together when burned in a furnace.

3. *Cannel Coal.*—This is a grade of bituminous coal that is very rich in hydrocarbons. The large percentage of volatile matter makes it valuable for gas making, but it is little used for the generation of steam, except near the places where it is mined.

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Bituminous and semibituminous coals are known to the trade by the following names:

Lump coal, which includes all coal passing over screen bars 1½ in. apart.

Nut coal, which passes over bars ¾ in. apart and through bars 1½ in. apart.

Pea coal, which passes over bars ⅝ in. apart and through bars ¾ in. apart.

Slack, which includes all coal passing through bars ¾ in. apart.

Lignite, according to the classification, comes under the general head of bituminous coal. Properly speaking, it occupies a position between peat and bituminous coal, being probably of a later origin than the latter. Exposure to the weather causes it to absorb moisture rapidly; it will then crumble quite readily. It is non-caking and yields but a moderate heat, and is, in this respect, inferior to even the poorer grades of bituminous coal.

Petroleum is occasionally used as a fuel, and, as such, possesses some advantages, among which are the ease of lighting and controlling the fire, the uniformity of combustion, and the economy in labor. Its disadvantages are: Danger of explosion, loss of fuel by evaporation, and high price in comparison with coal. The Standard Oil Company estimates that 173 gal. of petroleum is equal to 1 long ton (2,240 lb.) of coal, allowing for all savings incidental to its use.

Natural gas is abundant in parts of Ohio and Pennsylvania, and is there often used as a fuel for steam boilers, hot-air furnaces, etc. On an average, 30,000 cu. ft. of natural gas is the equivalent of 1 ton of coal.

Waste gases from the furnaces of rolling mills and from blast furnaces are extensively used. Naturally, their use is limited to the places where they are produced.

The Babcock & Wilcox Co. states that on the average 1 lb. of good bituminous coal may be considered as the equivalent of 2 lb. of dry peat, 2½ lb. of dry wood, 2½ to 3 lb. of dry tan bark or sun-dried bagasse, 3 lb. of cotton stalks, 3¾ lb. of straw, 6 lb. of wet bagasse, and from 6 to 8 lb. of wet tan bark,

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HEATING VALUE OF FUELS.

The heating value of a fuel is usually measured by the number of B. T. U. given out by the complete combustion of 1 lb. of the fuel. The average heating values, per pound of commonly used fuels, are:

	B.T.U.
Anthracite	13,500
Bituminous coal	14,000
Petroleum	20,500
Wood	7,400

The full heating value of a given fuel is not realized in practice. For house-heating work, between 8,000 and 9,000 B. T. U. per lb. of coal will be absorbed by the water at the ordinary combustion rate of from 4 to 8 lb. of coal per sq. ft. of grate surface per hr.

In power boilers, an average of 11,000 B. T. U. per lb. of coal is absorbed by the water. The reason for this difference in heat absorption is found in the different conditions of service. Heating boilers are operated under a dampened fire, in consequence of which there is an incomplete combustion of the coal during a large part of the time; power boilers, on the other hand, generate steam with a bright fire and very little incomplete combustion.

Assuming that in a heating boiler 8,000 heat units per lb. of coal, as ordinarily burned, will be absorbed by the water, and burning from 4 to 6 lb. of coal per sq. ft. of grate surface, from 32,000 to 48,000 B. T. U. per hr. will be absorbed per sq. ft. of grate surface. Since 1 sq. ft. of direct steam radiating surface requires about 300 B. T. U. per hr., 1 sq. ft. of grate is sufficient to insure a supply of steam for from 106 to 160 sq. ft. of radiating surface.

By increasing the combustion rate the same heating boiler will supply steam for an increased amount of radiation; but, to do so without making a proper increase in the amount of heating surface, and thus forcing the heater beyond its intended capacity, introduces a serious heat loss, due to the gases passing over the heating surfaces so fast that they give up only part of their available heat.

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BOILERS.

BOILER HEATING SURFACE.

The actual heating surface of a boiler includes all parts that have water on one side of the metal and gaseous products of combustion having a higher temperature than the water, on the other. Parts that are covered by steam instead of water on one side have little value in increasing the steam-generating capacity of the boiler.

The portion of the heating surface close to the fire, under the direct influence of the radiant heat, is much more effective in generating steam than that portion called the *indirect heating surface*, which is heated only by contact with the hot gases. The relatively great amount of indirect heating surface found in the majority of house-heating boilers is provided to utilize as much of the available heat as possible.

It is customary for manufacturers to rate heating boilers on the basis that 1 sq. ft. of heating surface is approximately equivalent to 10 sq. ft. of direct radiation, so that a boiler having 200 sq. ft. of heating surface would be rated to supply 2,000 sq. ft. of direct radiation.

The heating surface of return-tubular boilers may be calculated quite closely by the following:

Rule.—*Multiply two-thirds of the circumference of the shell, in inches, by its length, in inches; multiply the number of tubes by the length of the tube, in inches, and by its circumference; add to the sum of these products two-thirds of the area, in square inches, of the two tube sheets; from this sum subtract twice the area of all the tubes and divide the remainder by 144; the quotient represents the number of square feet of heating surface of the boiler.*

RATIO OF HEATING SURFACE TO GRATE AREA.

In practice, the ratio between the heating surface and grate area varies with the type of boiler and the rate of combustion. The following are average values:

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PROPORTIONS OF HEATING SURFACE TO GRATE SURFACE.

Type of Boiler.	Ratio = $\frac{\text{Heating Surface}}{\text{Grate Area}}$.
Plain cylindrical	12 to 15
Flue	20 to 25
Return-tubular	25 to 35
Vertical	25 to 30
Water-tube	35 to 40
Locomotive	50 to 100
Cast-iron sectional	10 to 30

RATIO OF HEATING SURFACE TO RADIATION.

In ordinary forms of house-heating boilers, from 1,800 to 2,400 B. T. U. are absorbed per sq. ft. of heating surface per hr., and since 1 sq. ft. of direct steam radiating surface requires from 250 to 330 B. T. U., say an approximate average of 300 B. T. U. per hr., it is evident that 1 sq. ft. of boiler-heating surface will generate enough steam to supply from 6 to 10 ft. of radiating surface. In other words, a vertical sectional boiler having 180 sq. ft. of heating surface will supply sufficient steam for 1,080 to 1,800 sq. ft. of direct radiation, including all losses due to condensation in the transmission of the steam through the supply piping.

GRATE AREA.

The area of grate surface required in any given case depends on the type of boiler employed, the amount of water to be evaporated, the nature and amount of coal to be burned, and the rate of combustion, which varies from 3 to 20 or more lb. of coal per sq. ft. of grate per hr. The required grate surface may be approximately determined by the following:

Rule.—*To find the grate surface, in square feet, divide the weight of steam, in pounds required per hour, by the product*

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obtained by multiplying the number of pounds of coal burned, per square foot of grate per hour, by the number of pounds of water evaporated per pound of coal.

In this rule no account has been taken of the difference in the number of B. T. U. required to evaporate water from different feedwater temperatures into steam at different pressures. The rule is therefore only approximate, but close enough for practical work. The average evaporation per pound of coal for different types of boilers is given in the following table:

AVERAGE EVAPORATION PER POUND OF COAL.

Type of Boiler.	Coal Burned per Hour per Square Foot of Grate Area.			
	6 to 10	10 to 14	14 to 18	18 to 20
	Water Evaporated per Pound of Coal. Pounds.			
Cylindrical	7.00	6.75	6.50	6.00
Two-flue	7.25	7.00	6.75	6.25
Return-tubular	9.00	8.50	8.25	8.00
Firebox	9.00	8.50	8.25	8.00
Vertical tubular	8.00	7.75	7.50	7.00
Water-tube	10.50	10.00	9.00	8.00
Cast-iron sectional	8.60			

RATIO OF GRATE SURFACE TO RADIATION.

The requisite area of grate necessary to supply a given amount of direct steam radiation may be found, approximately, by dividing the total amount of radiation surface by a factor varying between 100 and 160, selecting a factor in accordance with the character and probable management of the boiler. Ordinarily, heating boilers receive unskilful handling, a factor of 100 most nearly meeting the requirements, whereas with a skilled fireman in attendance a factor

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of 160 may be used with satisfactory results. For example, a heating boiler rated to supply 1,600 sq. ft. of direct radiation, including ordinary losses, should have a grate area of $\frac{1600}{100} = 16$ sq. ft. if operated under ordinary conditions, or $\frac{1600}{160} = 10$ sq. ft. if the boiler is to be carefully handled.

BOILER HORSEPOWER RATINGS.

Strictly speaking, there is no such thing as the horsepower of a boiler. The phrase was originally intended to mean that a boiler having a certain stated horsepower would furnish all the steam that was required to develop that amount of power in a given engine. This meant that if a certain boiler furnished steam for a 30-H. P. engine, it would be called a 30-H. P. boiler, and if the same boiler furnished steam for a 50-H. P. engine, it would be called a 50-H. P. boiler. It is therefore apparent that this rating had no particular significance.

Boilers are often rated by their ability to evaporate water from and at a temperature of 212° into dry steam, 34.5 lb. per hr. being reckoned as 1 H. P. This method, however, is merely an indirect way of arriving at the number of B. T. U. transmitted through the boiler. The rating of boilers by the number of B. T. U. actually transmitted per hour is one that permits of a direct comparison of the relative heating capacities of all kinds of steam and hot-water boilers.

In order to have a definite standard of comparison, the American Society of Mechanical Engineers has accepted the report of a committee recommending that 33,330 B. T. U. per hr. transmitted from the fuel and absorbed by the water shall constitute 1 boiler H. P. The horsepower of a boiler thus expressed is the measure of its performance under certain given conditions, and does not indicate its capabilities when employed under other conditions. For instance, a boiler employed in heating water in an open system, with a slow fire, would develop a much smaller horsepower than

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it would if employed in making high-pressure steam, with forced blast and intense fire. The standard boiler horsepower may be determined by the following:

Rule.—*Subtract the temperature of the feedwater, in degrees Fahrenheit, from the total heat of 1 lb. of steam above 32° at the pressure of the actual evaporation. Add 32 to the remainder and multiply this sum by the weight of water evaporated per hour into dry steam. Divide the product by 33,330.*

In rating boilers according to their heating surface, the following factors are commonly used:

PROPORTIONS OF HEATING SURFACE TO HORSEPOWER.

Type of Boiler.	Ratio = $\frac{\text{Sq. Ft. of Heating Surface}}{\text{Rated Horsepower}}$.
Plain cylindrical	6 to 10
Flue	8 to 12
Return-tubular	14 to 18
Vertical	15 to 20
Water-tube	10 to 12
Cast-iron sectional	10 to 18

SIZE OF BOILERS.

No hard and fast rules can be employed for determining the heating capacity of boilers, or for ascertaining the sizes best adapted for different jobs. The following table is deduced from practical tests and observations by Professor Carpenter, of Cornell University, and is considered to be within the limits of safety. Two cases are taken: (*a*) when the rate of coal consumption is 10 lb., and (*b*) when it is 8 lb. per sq. ft. of grate surface per hr. The latter is preferable for hot-water heating.

The usual dimensions of ordinary horizontal return-tubular power boilers, which often are used for steam-heating purposes, are given in the table headed "Specifications for Horizontal Tubular Boilers."

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PROPORTIONING PARTS OF HEATING BOILERS.—STEAM HEATERS.

Radiation by Feet.	250	500	750	1,000	1,500	2,000	3,000	4,000	5,000	7,500	10,000
Nominal horsepower	2.5	5	7.5	10	15	20	30	40	50	75	100
Radiating to heating surface	4.5	5.1	5.4	5.6	6	6.2	6.7	6.9	7 | 9*	7 | 9*	7 | 9*
Evaporation per lb. of coal	5.5	5.7	6	6.5	7	7.5	8	8.5	9	9.5	10
Lb. steam per sq. ft. grate *A*	55	57	60	65	70	75	80	85	90	95	100
Lb. steam per sq. ft. grate *B*	44	46	48	52	56	60	64	68	72	76	80
Radiating to grate surface *A*	165	171	180	195	210	225	240	255	270	285	300
Radiating to grate surface *B*	132	138	144	156	168	180	192	204	216	228	240
Heating to grate surface *A*	36.5	33.2	33.2	34.8	35	36.2	36.5	37.0	38.5	40.5 | 31.5*	42.5 | 33.3
Heating to grate surface *B*	28.5	27	27.7	27.7	28	29	28.5	29.6	30.8	32.7 | 25.6*	34.5 | 26.5*
Boiler heating surface, sq. ft.	55	98	138	178	250	322	447	580	710	1071 | 833*	1430 | 1111*
Grate surface, sq. ft. ..... *A*	1.52	2.92	4.15	5.68	7.15	8.9	12.4	15.7	18.5	26.5	33.3
Grate surface, sq. ft. ..... *B*	1.88	3.88	5.4	6.37	8.92	11.2	15.5	19.5	23.2	32.5	41.5
Diam. safety valve, in.	1.5	2.25	2.5	2.75	3	3.25	3.5	4	4	two 3-inch	two 4-inch
Diam. smoke pipe, in.	7	10	11	12	15	17	19	23	25	28	34

HOT-WATER HEATERS.

Radiating to heating surface	6.8	7.6	8.1	8.4	9	9.3	10	10.4	10.5	10.5 | 13.5*	10.5 | 13.5*
Radiating to grate surface *A*	247	256	270	292	315	337	360	382	405	427	450
Radiating to grate surface *B*	193	207	216	232	252	270	288	306	324	342	360
Heating to grate surface *A*	36.5	33.2	33.2	34.8	35	36.2	36.5	37	38.5	40.5 | 31.5	42.5 | 33.3
Heating to grate surface *B*	28.5	27	26.7	27.7	28	29	28.5	29.6	30.8	32.7 | 25.6*	34.5 | 26.5*
Heating surface, sq. ft.	36.5	65	91.5	118	166	215	296	385	470	703	905
Grate surface, sq. ft. ..... *A*	1	1.96	2.75	3.75	4.75	5.9	8.2	10.4	13.3	17.6	22.2
Grate surface, sq. ft. ..... *B*	1.25	2.58	3.6	4.25	5.9	7.1	10.3	13	15.3	21.5	27.5
Diam. smoke flue, in.	7	10	11	12	15	17	19	23	25	28	34

* Water-tube boiler.

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SPECIFICATIONS FOR HORIZONTAL TUBULAR BOILERS.

H. P. rating	15	20	25	30	35	40	45	50	60	70	80	100	125	150
Radiation rating (120 sq. ft. per H. P.)	1,800	2,400	3,000	3,600	4,200	4,800	5,400	6,000	7,200	8,400	9,600	12,000	15,000	18,000
Diam. of boiler, in.	36	36	42	44	44	44	48	54	54	60	60	66	72	72
Length of tubes, ft.	8	10	10	10	12	14	14	12	14	14	16	16	16	18
No. of tubes (3-in.)	28	28	38	46	46	46	46	58	58	76	76	94	116	116
No. of tubes (3½-in.)			28	34	34	34	38	46	46	60	60	76	94	94
No. of tubes (4-in.)			22	28	28	28	30	38	38	50	50	60	74	74
Thickness of shell	¼	¼	9/32	9/32	9/32	9/32	5/16	5/16	5/16	⅜	⅜	43/100	7/16	7/16
Thickness of heads	⅜	⅜	⅜	7/16	7/16	7/16	7/16	½	½	9/16	9/16	9/16	9/16	9/16
Diam. of dome	20	20	22	22	22	26	26	30	32	32	32	36	36	36
Height of dome	22	22	24	24	24	28	28	34	36	36	36	40	40	40
Diam. of stack, in.	16	16	20	22	22	24	24	26	28	28	28	30	34	36
Length of stack, ft.	28	35	35	35	40	50	50	40	50	50	60	60	60	60
Approx. weight of boiler	2,700	3,200	4,250	4,650	5,200	6,300	7,150	7,750	9,150	10,480	11,900	14,400	16,600	17,900
Approx. weight of boiler fixtures	2,000	2,700	3,250	3,450	3,700	4,100	4,250	4,450	4,850	5,120	5,600	6,200	7,400	7,700

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SAFETY-VALVE AREAS, IN SQUARE INCHES PER SQUARE FOOT OF GRATE SURFACE.

Gauge Pressure. Lb.	Area. Sq. In.	Gauge Pressure. Lb.	Area. Sq. In.
2	1.18	40	.53
4	1.11	50	.47
6	1.04	60	.42
8	.99	70	.38
10	.94	80	.34
15	.83	90	.31
20	.75	100	.28
25	.68	125	.26
30	.63	150	.24

BOILER SETTINGS.

Boilers used for heating buildings of moderate size usually have what is termed a *portable setting;* i. e., they are mounted, without brickwork, on cast-iron bases that may be extended to accommodate any increase of capacity of the boiler, made by adding other sections, when the demand for steam becomes greater than the original size of the boiler may have been designed to supply. Vertical cast-iron boilers having slab sections require no outer casing, although they are sometimes set in brickwork to prevent loss of heat, or to utilize the extreme outer surfaces of the sections as indirect heating surface. As a rule, however, an external covering of some non-conducting covering, such as magnesia and asbestos, is used in place of a brickwork setting, effectively preventing serious loss of heat from the exterior surfaces of the boiler.

The setting of a 60-in., return-tubular boiler with a half-arch front, as designed by the Hartford Steam Boiler Inspection and Insurance Company, is shown in the accompanying illustration. The foundation is heavy stonework laid to a depth of 3 or 4 ft. below the surface. On top of this is laid the brickwork. The side and rear walls are double, with a 2-in. air space between the inner and outer parts. The inside

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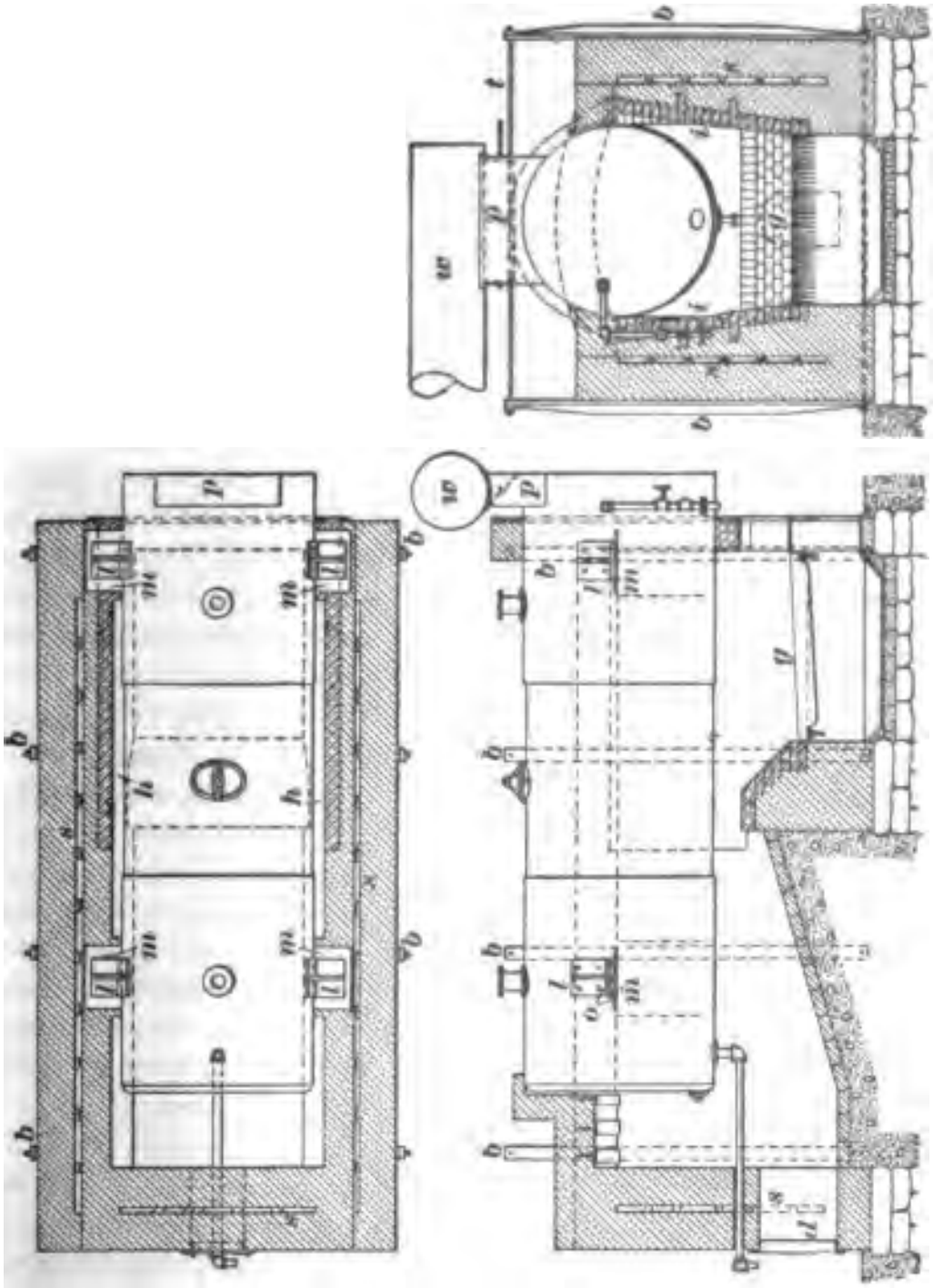
wall *i*, next to the furnace, is faced with firebrick, as is also the bridge and all portions in direct contact with the flames.

The boiler is supported by cast-iron lugs *l* riveted to the shell; these lugs rest on iron plates *m* placed on the top of



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the side walls. The front lugs rest directly on the plates, but the back lugs rest on rollers *o* of 1-in. round iron. The boiler is thus free to expand and contract. The rear wall is 24 in. from the rear head of the boiler, so as to allow the gases an opportunity to enter the tubes; above the tubes, however, the wall is built in to meet the head, and forms a roof for the chamber. The rear wall is provided with a door *d* for removal of the dirt and soot that collects back of the bridge and to provide a means of inspection.

The grate *g* is placed 24 in. below the shell; this is a sufficient distance for anthracite, but for bituminous coal it might better be 30 to 36 in. The grate has a fall of 3 in. from front to rear, which facilitates the admission of air to the rear of the grate and makes it somewhat easier to clear the spaces between the grate bars from below. The back end of the boiler should be set about 1 in. lower than the front end; this insures a thorough draining of the boiler when the blow-off is open.

The brickwork is closed into contact with the shell at the level of the center of the upper row of tubes; this prevents the gases coming in contact with the plates above the water-line. Some boilermakers prefer to make a brickwork arch over the top of the boiler and to allow the gases to pass back to the rear through the flue thus formed. The practice is risky, as it may lead to the overheating of the upper plates. A safe rule is "Never expose to fire or gases of combustion any part of the shell not completely covered with water." This rule applies to the blow-off pipe as well; in order to prevent its destruction by the gases of combustion and the heat, it should always be protected either by being covered with a larger pipe or by a cast-iron sleeve, or by being bricked in. The last method has the serious objection that it interferes with the examination of the pipe, which may corrode badly, when bricked in, without it being discovered.

The brickwork is strengthened by buckstaves *b* held together by tie-rods *t*. The buckstaves are best made of wrought-iron channel or angle irons. It will be noticed that in the present case the flue pipe *p* is rectangular, but the

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pipe *w* leading to the chimney is cylindrical. The purpose of the air space *s* is to prevent the conduction of heat to the outer walls and thus keep them cool. Its utility is somewhat doubtful and many of the best boilermakers do not recommend it.

APPROXIMATE NUMBER OF BRICKS REQUIRED FOR SETTINGS OF RETURN-TUBULAR BOILERS.

Horsepower.	Half-Front Setting.		Full-Front Setting.	
	Number of Bricks Required Above Floor Level.		Number of Bricks Required Above Floor Level.	
	Red Brick.	Firebrick.	Red Brick.	Firebrick.
10	3,400	500	4,800	500
12	3,900	590	5,350	590
15	4,200	650	6,000	650
20	4,800	700	7,000	700
25	5,500	750	8,000	750
30	7,200	800	9,000	800
35	7,700	900	10,400	900
40	9,100	950	11,750	950
45	11,000	1,000	13,800	1,000
50	12,000	1,100	14,600	1,100
60	13,200	1,350	17,000	1,350
70	14,500	1,400	19,000	1,400
80	16,000	1,400	21,000	1,400
90	17,000	1,500	22,200	1,500
100	17,500	1,550	23,000	1,550
125	19,000	1,700	25,000	1,700
150	20,000	1,800	26,500	1,800

CHIMNEYS.

The *chimney* serves the double purpose of creating a draft and carrying away obnoxious gases.

The draft pressures ordinarily produced by chimneys vary from 0 to 2 in. of water. A water-gauge pressure of 1 in. is equivalent to .03617 lb. per sq. in. To successfully burn anthracite, slack, or culm, a draft of 1¼ in. is necessary.

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SIZES OF CHIMNEYS AND HORSEPOWERS OF BOILERS.

Height of Chimney. Feet.											Actual Area. Square Feet.	Side of Square. Inches.	Diameter. Inches.
50	60	70	80	90	100	110	125	150	175	200			
Commercial Horsepower.													
23	25	27									1.77	16	18
35	38	41									2.41	19	21
49	54	58	62								3.14	22	24
65	72	78	83								3.98	24	27
84	92	100	107	113							4.91	27	30
	115	125	133	141							5.94	30	33
	141	152	163	173	182						7.07	32	36
		183	196	208	219						8.30	35	39
		216	231	245	258	271					9.62	38	42
			311	330	348	365	389				12.57	43	48
			363	427	449	472	503	551			15.90	48	54
			505	539	565	593	632	692	748		19.64	54	60
				658	694	728	776	849	918	981	23.76	59	66
				792	835	876	934	1,023	1,105	1,181	28.27	64	72
					995	1,038	1,107	1,212	1,310	1,400	33.18	70	78
					1,163	1,214	1,294	1,418	1,531	1,637	38.48	75	84
					1,344	1,415	1,496	1,639	1,770	1,893	44.18	80	90
					1,537	1,616	1,720	1,876	2,027	2,167	50.27	86	96

EXAMPLE.—A round chimney 100 ft. high is to be used for a battery of boilers of 550 H. P. What should be the internal diameter?

SOLUTION.—Looking under column 100 in "Height of Chimney Feet," the nearest horsepower is 565, and the diameter corresponding is 60 in., which should be the internal diameter of the chimney. Ans.

The flue through which the gases pass from the furnace to the chimney should have an area equal to, or a little larger than, the area of the chimney. Abrupt turns in the flue and contractions in its area should be avoided, as they greatly increase the resistance to the flow of the gases.

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SIZE OF SQUARE CHIMNEYS FOR STEAM HEATING.

Square Feet of Direct Steam Radiation.	Approximate Equivalent in Horse-power.	Height of Chimney. Feet.								
		25	30	40	50	60	80	100	120	150
		Length of Side. Inches.								
100	1	6.9	6.8	6.6	6.5	6.4	6.2	6.1	6.0	5.9
300	3	9.1	8.9	8.6	8.3	8.1	7.8	7.6	7.4	7.3
500	5	10.6	10.3	9.8	9.5	9.3	8.9	8.6	8.4	8.2
700	7	11.8	11.4	10.9	10.5	10.3	9.8	9.5	9.3	9.0
1,000	10	13.3	12.9	12.3	11.8	11.5	11.0	10.6	10.3	9.9
1,500	15	15.5	14.9	14.1	13.6	13.1	12.5	12.0	11.7	11.3
2,000	20	17.1	16.4	15.7	15.1	14.6	13.8	13.3	12.9	12.4
3,000	30	20.1	19.3	18.3	17.5	16.9	16.1	15.4	14.9	14.3
4,000	40	22.6	21.8	20.5	19.6	18.9	17.9	17.0	16.6	15.9
5,000	50	24.8	23.9	22.4	21.5	20.7	19.6	18.7	18.0	17.3
6,000	60	26.8	25.7	24.2	23.1	22.3	20.2	20.1	19.4	18.5
7,000	70	28.6	27.5	25.9	24.7	23.8	22.4	21.4	20.6	19.7
8,000	80	30.3	29.1	27.4	26.1	25.1	23.6	22.6	21.8	20.8
9,000	90	31.9	30.6	28.8	27.1	26.4	24.9	23.7	22.8	21.8
10,000	100	33.4	32.1	30.1	28.7	27.6	26.0	24.8	23.9	22.8
12,500	125	36.9	35.4	33.2	31.6	30.4	28.6	27.2	26.2	25.0
15,000	150	40.0	38.4	36.0	34.3	32.9	30.9	29.5	28.3	27.0

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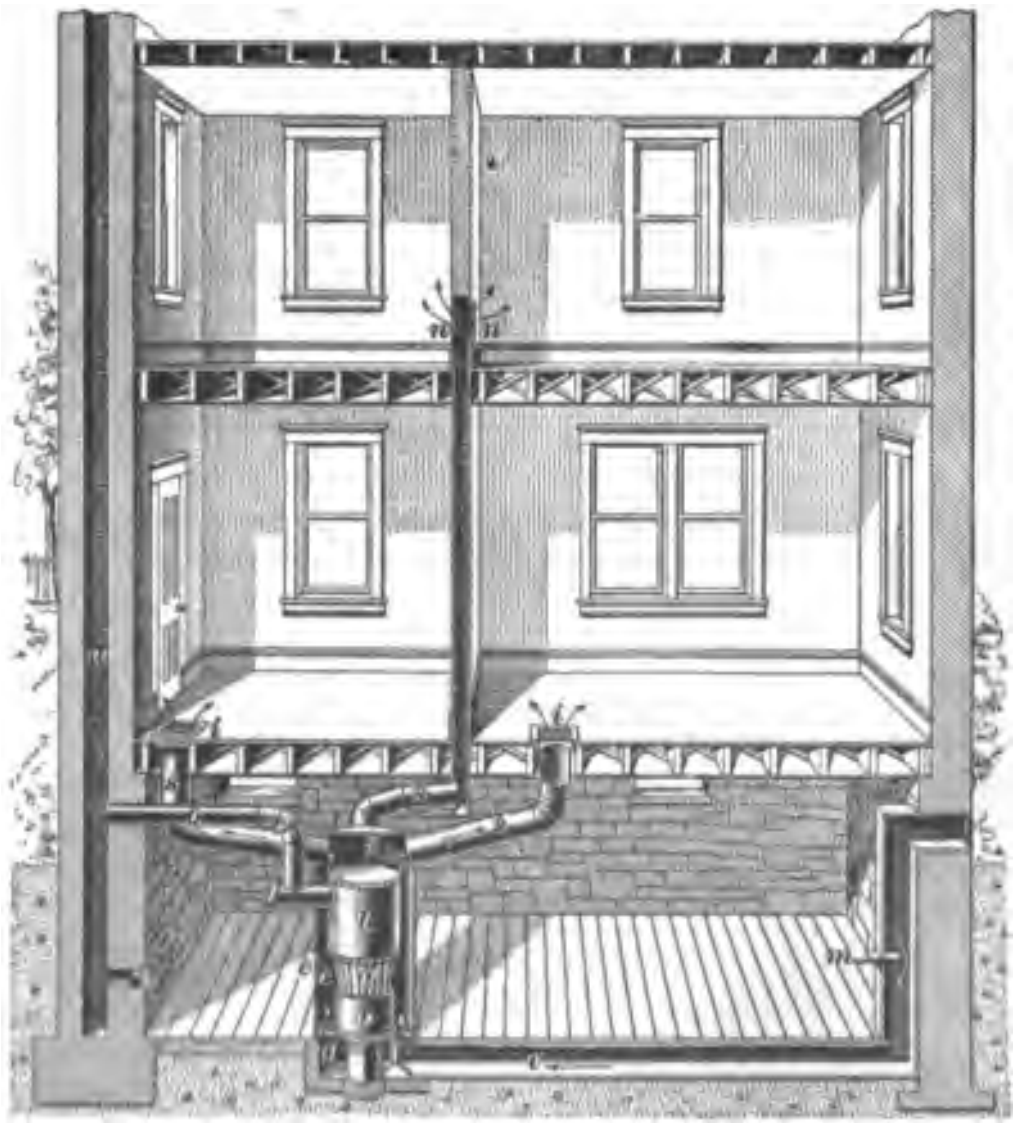
HOT-AIR FURNACE HEATING.

GENERAL DESCRIPTION.

The method of warming buildings by hot-air furnaces may be briefly described as one in which air passed over heated surfaces within a furnace and warmed thereby is distributed



to the various rooms throughout the building by means of metal pipes or ducts, as indicated in the accompanying illustration. Ordinarily, the only motive force producing the

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flow of air is that due to the difference in density, or weight, between that of the heated air and that of the outer atmosphere. In other words, on being heated the air expands and thereupon becomes lighter, being forced upwards from the furnace into the rooms to be warmed by the pressure due to the greater density of the outer atmosphere. This method is known as the *gravity system* of furnace heating.

When, instead of utilizing the force of gravity, a fan or blower is used to force the air over the furnace and through the ducts, the method is known as the *fan-furnace system* of heating. The *internal circulation system* of furnace heating is one wherein a supplemental air-supply duct is arranged between the furnace and the first floor of the dwelling, so that at night, or on extremely cold days, the supply of air to the furnace is taken from within the building.

The hot-air furnace, a common form of which is shown in the illustration, is essentially composed of a firebox *a*, combustion chamber *b*, an air space *c* surrounding them, an ash-pit *r*, and a jacket *e* enveloping the whole. The lower end of the air space *c* communicates with the outer atmosphere by a cold-air duct *v*, through which fresh air enters the air space of the furnace by way of the cold-air pit *g*. The slide *m* in the cold-air duct *v* is provided for shutting off the supply of fresh air. The air is heated by contact with the heated plates or castings that envelop the firebox and combustion chamber. Hot-air pipes *s*, *s*, etc. are attached to the top of the jacket to convey heated air from the air space to the rooms to be warmed, the air being discharged through floor registers *i*, *i*, or by wall registers *n*, *n*. The chief object to be considered in putting together the parts that form the firebox *a*, combustion chamber *b*, and ash-pit *r*, is to make the joints permanently gas-tight, so that the gases of combustion will not have access to the air space *c* through open joints. The products of combustion flow from *b* through the smoke pipe *o* to the chimney *u*, and escape to the atmosphere.

Hot-air furnaces are usually supplied with a water pan, placed inside the jacket, for moistening the heated air.

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RULES FOR PROPORTIONING FURNACE HEATING SYSTEMS.

Rules for Grate Surface.—There are various empirical rules in common use for determining the amount of grate surface a furnace should have; some of the best ones are here given.

Rule I.—*Divide the number of cubic feet representing the total volume of air to be heated per hour by 100. The quotient will be the required grate surface, in square inches.*

Rule II.—*The sum of the glass surface and equivalent glass surface, in square feet, equals the required grate surface, in square inches.*

Rule III.—*Divide the number of B. T. U. required per hour to heat the building to 70° during the coldest weather by 180 for furnaces in ordinary dwellings, or by 270 if a fireman or janitor is constantly employed tending the furnace. The quotient is the grate surface, in square inches.*

These empirical rules should give good results in all ordinary-size furnaces that have a sufficient amount of heating surface properly arranged. In small furnaces, the grate surface may be a little in excess of that found by the above rules.

In calculating the number of B. T. U. lost per hour, it is good practice to figure on changing the air in the building four times per hour.

Furnace Proportions.—Some furnaces are fairly well proportioned, while others are very defective. In some of them the heating surface is altogether too small for the amount of grate surface. The following table has been compiled after a careful examination of a large number of furnaces; it shows the relative average proportions that should exist between the most important parts in order to obtain satisfactory results in heating.

The proportions shown in this table are based on a combustion of about 3 lb. of coal per sq. ft. of grate surface per hr., and a furnace efficiency of about 70 per cent. This rate of combustion may appear low, but it is an ordinary rate for an ordinary fire. When the rate of combustion is much higher

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than 3 lb., the fire requires attention too often. The heating surface given in the table is larger than is found in most furnaces, but it is not too large for good results.

Furnace Efficiency.—The efficiency of a furnace is an indication of its ability to impart the heat of the burning coal to the air passing over the heated surfaces. The efficiency of a given furnace is a quantity varying largely with existing conditions, such as the kind of coal used, the chimney draft, and the quality of the attendance. It is found by dividing the number of B. T. U. per pound of coal usefully applied by the number of B. T. U. a pound of the coal used is capable of emitting. Thus, if a certain coal is capable of emitting 14,000 B. T. U. per lb., and only 7,000 B. T. U. are absorbed by the air as it passes over the heated surfaces of the furnace, the efficiency of the furnace is $7{,}000 \div 14{,}000 = .5 = 50$ per cent.

To measure the amount of heat transmitted from a furnace to the rooms it is necessary to measure the volume of air passing through the cold-air box and to record its temperature. Then, the mean temperature of the hot air and its volume per hour at each register is measured. Next is calculated the number of B. T. U. required to raise the different volumes of warm air delivered per hour at each register from the temperature of the cold air as it enters the

PROPORTIONS REQUIRED IN FURNACE HEATING.

Glass surface and equivalent, sq. ft.	125	150*	200	250	500	750	1,000
Volume of air to be heated per hr., cu. ft.	10,000	12,000	16,000	20,000	40,000	60,000	84,000
Space to be warmed, cu. ft.	2,500	3,000	4,000	5,000	10,000	15,000	21,000
Furnace heating surface, sq. ft.	53	62	85	106	212	320	425
Grate area, sq. in.	106	124	170	212	424	640	850
Smoke pipe diameter, in.	6	6	7	7	8	9	10

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cold-air box to the temperature found by actual measurement at each register face. The B. T. U. thus separately found are added and the sum represents the total amount of heat given off by the furnace to the air per hour.

SIZE OF HOT-AIR PIPES AND STACKS.

Size of Leaders.—The size of the leaders is influenced by their location, and their area should be made larger than that of the stacks they supply, on account of the extra friction encountered by the air in traveling in a horizontal direction.

In ordinary dwellings, the requirements of ventilation are not usually considered, it being assumed that the amount of air required for heating purposes is also sufficient for ventilation.

There are various empirical rules for determining the sizes of hot-air leader pipes, but no single rule gives satisfactory results in all cases. The following rule simplifies calculation, saves time, and gives satisfactory results for ordinary work. It is known as the I. C. S. rule for leader pipes, and may be remembered by the numerals 1-10-100.

Rule.—*Add together the area of the exposed glass surface, in square feet, the area of the exposed wall surface, in square feet, divided by 10, and the volume of the room, in cubic feet, divided by 100; the sum will be the area of pipe required, in square inches, for the first floor.*

For the second-floor leaders, multiply the sum found by this rule by .8, and for the third floor, by .6. For north or west exposure increase the leader-pipe area 10 per cent.

A rule frequently used for rooms having an excess of exposed glass and wall surface bases the size of the leader pipe on the cooling surface only, and is as follows:

Rule.—*For rooms on the first floor, add together the total glass surface and one-fourth the area of the exposed wall, in square feet; the sum is the proper area of the pipe, in square inches.*

For second-story rooms, multiply by .75 for a south and east exposure; for third-story rooms, multiply by .5 for a south and east exposure, and by .75 for a north and west exposure.

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In a rule used by many furnacemen, the cooling surfaces are converted into an equivalent of the cubic contents of the room to be heated. 1 sq. ft. of cold floor surface is considered to equal 1 cu. ft.; 1 sq. ft. of outside wall surface is taken to equal 3 cu. ft.; 1 sq. ft. of outside door surface is considered as equal to 6 cu. ft.; and 1 sq. ft. of outside glass surface is considered equivalent to 12 cu. ft. The rule is as follows:

Rule.—*Find the cubic contents equivalent to the cooling surfaces and add them to the cubic contents of the room, in cubic feet; divide the sum by 40. The quotient will be the sectional area of the leader pipe, in square inches. Add 10 per cent. for a north and west exposure.*

Some furnacemen determine the area of the hot-air pipe, in square inches, by dividing the cubic contents of the room, in cubic feet, by a constant taken from the following table:

CONSTANTS FOR PROPORTIONING HOT-AIR PIPES.

Rooms.	Constant.
First-floor rooms, moderate exposure	30
First-floor rooms, great exposure	20–25
Second-floor rooms	25–35
Third-floor rooms	30–40

In the rule given below, the cubic contents and different cooling surfaces are reduced to an equivalent glass surface (abbreviated to E. G. S.), the following value being assigned the different quantities:

12 cu. ft. of contents = 1 sq. ft. of glass surface;
12 sq. ft. of cold floor = 1 sq. ft. of glass surface;
4 sq. ft. of exposed wall = 1 sq. ft. of glass surface;
2 sq. ft. of outside door surface = 1 sq. ft. of glass surface.

Rule.—*To find the area of leader pipe, in square inches, multiply the sum of the actual and equivalent glass surface of the room by .8. For a north or west exposure add 10 per cent. to the area.*

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If the different rules for finding the size of hot-air leader pipes here given be applied to the same room, their results may agree very closely, or there may be an appreciable divergence, depending on the conditions of the case. In case of a large divergence, it may be well to take an average.

Size of Stacks.—For the first floor, the stack should have the same area as the leader pipe. A stack leading to the second floor may have .8 of the area of the leader pipe, and a stack leading to the third floor .6 to .7 the area of the leader pipe. Stacks should have their sectional area increased 10 per cent. for each offset.

Sizes of Registers.—In calculating the size of register necessary for a given stack or pipe, only two-thirds the area corresponding to the size given by manufacturers in their catalogue list should be regarded as effective, on account of the obstruction offered by the grille-work, and by the body and valves.

AREA OF RECTANGULAR REGISTERS.

Size of Opening. Inches.	Net Area. Square Inches.	Size of Opening. Inches.	Net Area. Square Inches.
6 × 10	40	14 × 22	205
8 × 10	53	15 × 25	250
8 × 12	64	16 × 24	256
8 × 15	80	20 × 20	267
9 × 12	72	20 × 24	320
9 × 14	84	20 × 26	347
10 × 12	80	21 × 29	400
10 × 14	93	27 × 27	486
10 × 16	107	27 × 38	684
12 × 15	120	30 × 30	600
12 × 19	152		

For instance, a 10-in. pipe, which has a sectional area of about 79 sq. in., requires at least a 10″ × 12″ register. A 10″ × 14″ size, however, is better, as it offers less resistance to the passage of the air. When the velocity of the air-current issuing from the register is liable to be unpleasantly high, it

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may be reduced one-half at the point of exit by doubling the capacity of the register box and the pipe for a short distance from the outlet. In designating registers, the sizes are taken from the outside of the register face. The clear opening is about two-thirds the register face.

AREA OF ROUND REGISTERS.

Diameter of Opening. Inches.	Net Area. Square Inches.	Diameter of Opening. Inches.	Net Area. Square Inches.
7	26	16	134
8	33	18	169
9	42	20	209
10	52	24	301
12	75	30	471
14	103	36	679

The following table shows the sizes of registers and leader pipes commonly employed in ordinary dwellings:

SIZE OF HOT-AIR PIPES AND REGISTERS.

First-Floor Rooms.				Second-Floor Rooms.			
Size of Register. Inches.	Diameter of Pipe. In.	Size of Rooms. Feet.	Height of Ceiling. Feet.	Size of Register. Inches.	Diameter of Pipe. In.	Size of Rooms. Feet.	Height of Ceiling. Feet.
12×15	12	16×16 to 18×20	11	10×14	10	16×16 to 18×20	10
10×12 or 10×14	10	14×14 to 15×15	10	9×12	9	14×14 to 16×16	9
9×12	9	12×12 to 14×15	9	8×12	8	10×10 to 13×14	8
8×12	8	8×12 to 13×13	9	8×10	7	7×12 to 12×12	8

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ıe heating engineers proportion the registers to the ɔ contents of the room to be warmed; the free area of ɟister, in square inches, per 1,000 cu. ft. of space for different ɾelocities of air discharge from the registers and for different numbers of air changes per hour are given in the accompanying table.

REGISTER PROPORTIONS IN REFERENCE TO CUBIC CONTENTS.

Air Changes per Hour.	Velocity, in Feet per Minute.									
	60	120	180	240	300	360	480	600	900	1,200
	Net Free Area of Register, in Square Inches, for Each 1,000 Cu. Ft. of Space.									
1	40	20	13.3	10	8	6.7	5	4	2.7	2
2	80	40	26.0	20	16	13.0	10	8	5.3	4
3	120	60	40.0	30	24	20.0	15	12	8.0	6
4	160	80	53.0	40	32	27.0	20	16	11.0	8
5	200	100	66.0	50	40	33.0	25	20	13.0	10
6	240	120	80.0	60	48	40.0	30	24	16.0	12
8	320	160	107.0	80	64	53.0	40	32	21.6	16
10	400	200	133.0	100	80	67.0	50	40	27.0	20
12	480	240	160.0	120	96	80.0	60	48	32.0	24

STEAM HEATING

TRADE TERMS

Pipes that serve to convey steam from the boiler, or other source of supply, and distribute it to several branches are known as *steam mains*. They are usually run along the cellar ceiling, being hung from the first-floor beams by adjustable iron hangers. They pitch downwards from the highest point near the boiler to the lowest point at the farther end of the mains. The pitch should be at least ¼ in. in 10 ft., so that the water of condensation may freely flow to the lower end of the main.

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An *overhead main* is a steam main that is run horizontally, or nearly so, at an elevation higher than the radiators that it supplies.

Risers are vertical pipes that rise from floor to floor to convey steam from the steam main to the radiators or coils on the several floors. *Drop risers* are those in which the steam flows downwards to the radiators or coils from a steam main above, usually in the attic.

A *return main* is a nearly horizontal line of pipe, usually run near or under the cellar floor; it receives all water of condensation from the heating system and returns it to the boiler, or otherwise disposes of it.

A *dry return main* is one that is run above the water-line of the boiler and, consequently, is partly filled with steam.

A *wet return main* is one that is run below the water-line and is filled with water at all times. As a rule, this is more reliable than a dry return main, except in places where the main is subject to frost.

Return risers are those vertical pipes that receive the water of condensation from the radiators or coils on the several floors of a building and convey it to the return main.

A *drip pipe*, *relief*, or *bleeder*, is a small pipe used to drain water of condensation from the foot of the risers or from a low point, pocket, or trap in the main steam pipes.

Riser connections are the pipes, usually short and nearly horizontal, that connect the steam main to the lower ends of the risers or that connect an overhead main to the upper ends of drop risers.

Radiator connections are the pipes that connect the radiators to the risers or mains; they are usually short and seldom larger than 2-in. pipe.

Direct radiation is a term applied to all kinds of coils and radiators placed inside the rooms to be heated.

Indirect radiation is a term applied to all kinds of coils, radiators, and other forms of heating surfaces located outside the rooms to be warmed. Indirect radiators are usually hung from the cellar ceiling, are encased with a galvanized sheet-iron jacket, and are so constructed that fresh air from

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the outer atmosphere flows between the heating surfaces and enters the room, thus providing ventilation as well as heat.

Direct-indirect radiation, sometimes called *semidirect*, is a term applied to radiators and coils located in the rooms to be warmed and provided with connections to the outer atmosphere, so that fresh air may enter the rooms through the radiator flues and be warmed thereby.

METHODS OF HEATING BY STEAM.

The various systems of heating by steam may be classed in a general way as (1) *high-pressure systems;* (2) *low-pressure systems;* (3) *vacuum*, or *exhaust*, *systems*.

In the first class are all systems of heating operated at a pressure greater than 10 lb. by the gauge; in the second class are those operated at pressures between that of the atmosphere and 10 lb. by the gauge; in the third class are all systems operated at a pressure lower than that of the atmosphere. Any one of these systems may be subdivided as follows: (1) the one-pipe system; (2) the two-pipe system; (3) the two-pipe system with separate risers; (4) the overhead-main or drop-supply system. These, in turn, may be gravity-return systems or forced-return systems, and they may have wet-return or dry-return mains. In the *gravity-return system*, the water of condensation flows back to the boiler by gravity. This is used in cases where the full boiler pressure is allowed on the heating system. It cannot be used elsewhere.

The *forced-return system* is that in which the water of condensation is forced back to the boiler from the return mains of the heating system by a pump, steam loop, steam-return trap, or other such contrivance. This system is used when the boiler pressure is higher than that in the heating system, as, for example, when a pressure-reducing valve is used on the steam-supply pipe to the heating system.

A common arrangement of the *one-pipe system* of heating is shown in Fig. 1. The boiler *a* furnishes steam to the steam main *b*, by which it is conveyed to the several risers *c*, *c*, thence flowing to the radiators *d*, *d*, etc. within the rooms to

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be warmed. The main *b* is so suspended from the floor joists by hangers as to have a uniform fall from its highest point, which is immediately above the boiler, to its lowest point *f*. A pitch of about ¼ in. in 10 ft. is usually considered a sufficient fall for the main. When steam is generated in the boiler, it

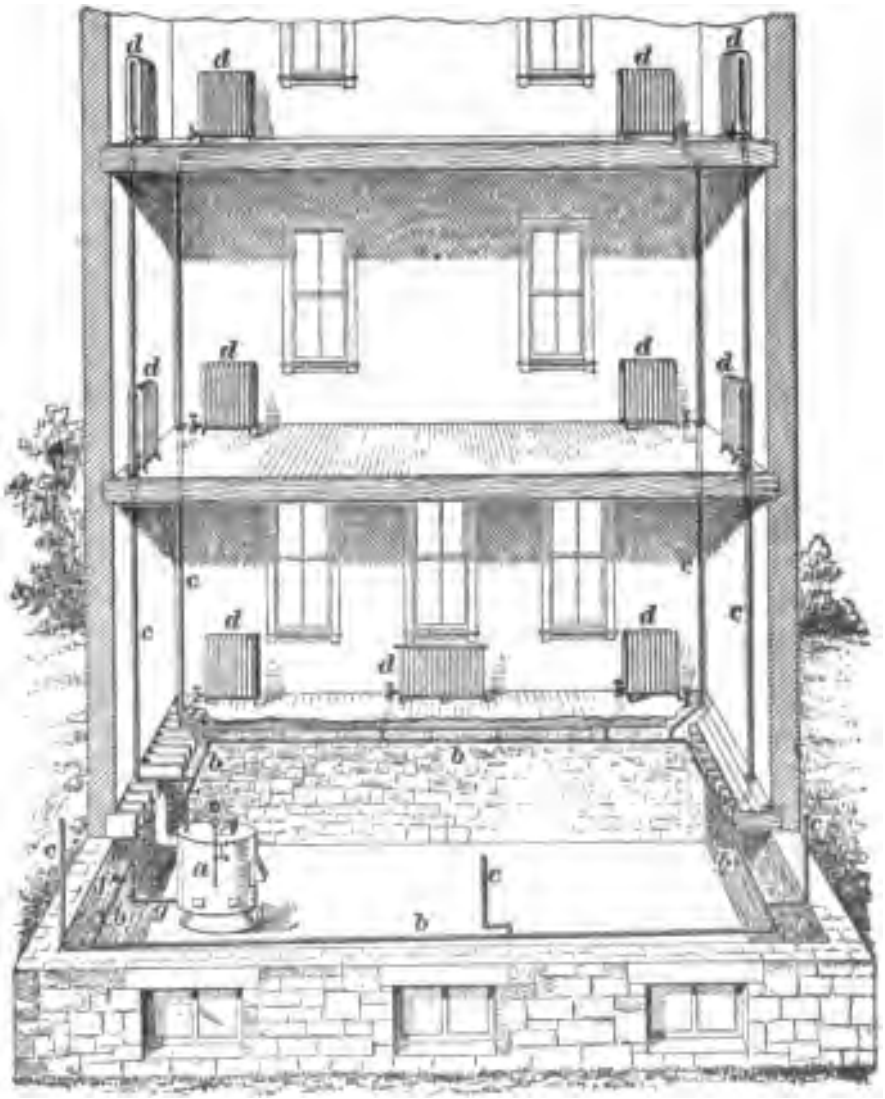

FIG. 1.

is forced into the steam main, from there into the risers, and thence into the radiators. The air that the pipes contain is forced out of the system to the atmosphere through air vents placed at suitable points in the system, usually on each

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radiator at the end opposite the steam inlet. As steam flows through the main and the risers, part of it will be condensed

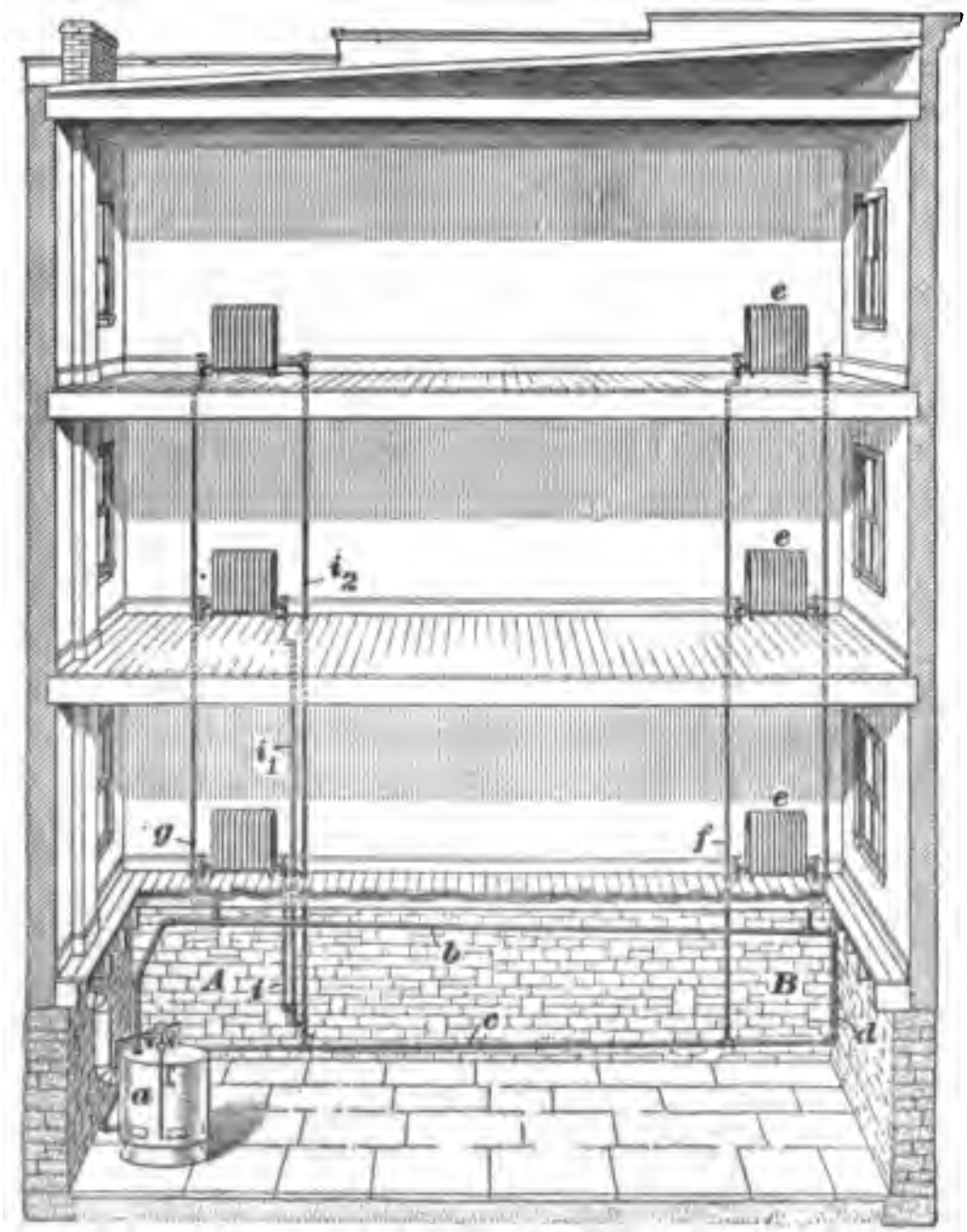

FIG. 2.

and the water of condensation will fall by gravity to the bottom of the steam main, flow to its lower end *f*, and enter the bottom of the boiler through the return pipe *g*. The water

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of condensation from the radiators first accumulates in the base of the radiators until a sufficient hydrostatic head is formed to cause it to flow out of the radiators against the inflow of the steam. It then falls down the risers, through the riser connections, and into the steam main, also against the flow of the steam. If the riser connections to the steam main or radiator connections to the riser have too little pitch, or if the pipes are too small, the flow of the water of condensation through them will be resisted to such an extent by the flow of steam that the water will not flow off as quickly as it is formed, the result of which will be that the water will accumulate in the pipe until it entirely closes it, when water hammer will take place. The steam main should be made sufficiently large to prevent such a difference between the pressure in the boiler and that at the point *f* as will cause the water to back up in the main and retard the flow of steam to any riser connection.

The *two-pipe system* is illustrated by the risers and radiator connections at the right of Fig. 2. Each radiator has two connections, one of which serves as an inlet for steam and the other as an outlet for water of condensation.

One of the many modifications of the two-pipe system is that known as the *separate-return system* shown at the left of Fig. 2. From the boiler *a* the return main *b* pitches downwards to the point at which connection with the return main *c* is made by the relief pipe *d*.

It will be observed that in the method of piping radiators *e*, *e*, *e*, the radiator return connections discharge into the same return riser *f* above the water-line. Consequently, steam is liable to flow from one radiator into another by way of the return riser. This is objectionable, because the inflow of steam to any of the radiators against the outflow of the water of condensation tends to cause the water to back into the radiator and thus flood it.

When a radiator is double-piped there should be a continuous inflow of steam through the inlet only and an outflow of water of condensation through the outlet only, the water and steam always flowing in an unchanging

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direction. This, however, is not always accomplished when the radiators are connected up by the two-pipe method shown at *B*.

In order to obtain a positive circulation through the radiators and throughout the system, the return riser from each radiator may be continued down separately and connected

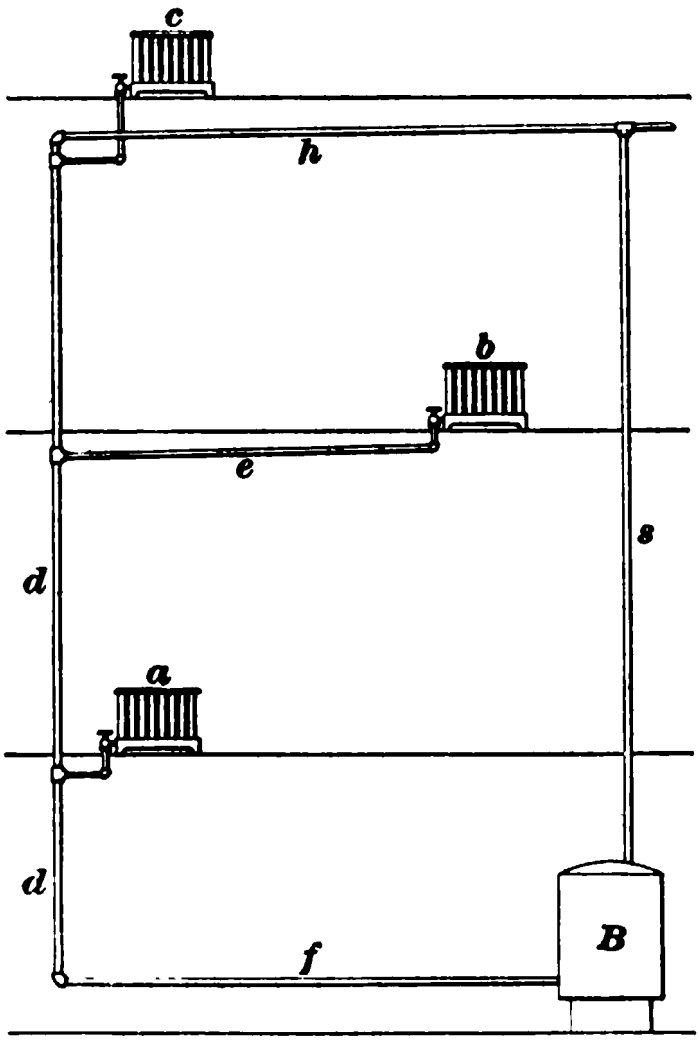

FIG. 3.

together below the level of the boiler water-line, as shown at i, i_1, i_2.

The *drop system*, sometimes called the *Mills system*, is shown in Fig. 3. The steam supply passes up the riser *s* to the top of the system, thence along the horizontal branch main *h*, and descends through the drop riser *d*. The radiators have

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single-pipe connections to the steam supply. The water of condensation in the pipes h, d moves in the same direction as the steam, instead of in the opposite direction, as in the single-pipe system.

PIPING DETAILS.

Standard Pipe Threads.—What is known as the Briggs standard pipe threads have an angle of 60°, and are rounded off slightly at the top and bottom, so that the depth of the thread is only four-fifths as great as it would be if the threads were sharp. The outside surface of the pipe is tapered to a

PROPORTIONS OF STANDARD PIPE THREADS.*

Nominal Sizes of Pipe. Inches.	Threads per Inch.	Total Length of Thread. Inches.	Length of Perfect Thread. Inches.	Diameter at End of Pipe.	
				Outside. Inches.	At Bottom of Thread. Inches.
⅛	27	.41	.19	.393	.342
¼	18	.62	.29	.522	.445
⅜	18	.63	.30	.656	.579
½	14	.83	.39	.816	.717
¾	14	.84	.40	1.025	.926
1	11½	1.03	.51	1.283	1.162
1¼	11½	1.06	.54	1.626	1.505
1½	11½	1.07	.55	1.866	1.745
2	11½	1.10	.58	2.339	2.218
2½	8	1.64	.89	2.819	2.646
3	8	1.70	.95	3.441	3.268
3½	8	1.75	1.00	3.938	3.765
4	8	1.80	1.05	4.434	4.261
4½	8	1.85	1.10	4.931	4.758
5	8	1.91	1.16	5.491	5.318
6	8	2.01	1.26	6 546	6.373
7	8	2.11	1.36	7.540	7.367
8	8	2.21	1.46	8.534	8.361
9	8	2.32	1.57	9.527	9.354
10	8	2.43	1.68	10.645	10.472

*For actual external and internal diameters, thickness of metal, etc., see table of standard dimensions of wrought-iron pipe.

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STANDARD DIMENSIONS OF WROUGHT-IRON STEAM, GAS, AND WATER PIPE.

Diameter.			Thickness.	Circumference.		Transverse Areas.			Length of Pipe per Square Foot of		Length of Pipe Containing 1 Cu. Ft.	Nominal Weight per Foot.
Nominal Internal. Inches.	Actual External. Inches.	Actual Internal. Inches.	Inch.	External. Inches.	Internal. Inches.	External. Sq. In.	Internal. Sq. In.	Metal. Sq. In.	External Surface. Feet.	Internal Surface. Feet.	Feet.	Pounds.
⅛	.405	.270	.068	1.272	.848	.129	.0573	.0717	9.440	14.150	2513.000	.241
¼	.540	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.490	1383.300	.420
⅜	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.730	751.200	.559
½	.840	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.130	472.400	.837
¾	1.050	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.000	1.115
1	1 315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.900	1.668
1¼	1.660	1.380	.140	5.215	4.335	2.164	1.4960	.6680	2.301	2.768	96.250	2.244
1½	1.900	1.611	.145	5.969	5.061	2.835	2.0380	.7970	2.010	2.371	70.660	2.678
2	2.375	2.067	.154	7.461	6.494	4.430	3.3560	1.0740	1.608	1.848	42.910	3.609
2½	2.875	2.468	.204	9.032	7.753	6.492	4.7840	1.7080	1.328	1.547	30.100	5.739
3	3.500	3.067	.217	10.996	9.636	9.621	7.3880	2.2430	1.091	1.245	19.500	7.536
3½	4.000	3.548	.226	12.566	11.146	12.566	9.8870	2.6790	.955	1.077	14.570	9.001
4	4.500	4.026	.237	14.137	12.648	15.904	12.7300	3.1740	.849	.949	11.310	10.665
4½	5.000	4.508	246	15.708	14.162	19.635	15.9610	3.6740	.764	.848	9.020	12.340
5	5.563	5.045	.259	17.477	15.849	24.306	19.9900	4.3160	.687	.757	7.200	14.502
6	6.625	6.065	.280	20.813	19.054	34.472	28.8880	5.5840	.577	.630	4.980	18.762
7	7.625	7 023	.301	23.955	22.063	45.664	38.7380	6.9260	.501	.544	3.720	23.271
8	8.625	7.982	.322	27.096	25 076	58.426	50.0400	8.3860	.443	.478	2.880	28.177
9	9.625	8.937	.344	30.238	28.076	72.760	62.7300	10.0300	.397	.427	2.290	33.701
10	10.750	10.019	.366	33.772	31.477	90.763	78.8390	11.9240	.355	.382	1.820	40.065
11	11.750	11.000	.375	36.914	34.558	108.434	95.0330	13.4010	.325	.347	1.510	45 028
12	12.750	12.000	.375	40.055	37.700	127.677	113.0980	14.5790	.299	.319	1.270	48.985
13	14.000	13.250	.375	43.982	41.626	153.938	137.8870	16.0510	.273	.288	1.040	53.921
14	15.000	14.250	.375	47.124	44.768	176.715	159.4850	17.2300	.255	.268	.903	57.893
15	16.000	15.430	.284	50.260	48.480	201.060	187.0400	14.0200	.239	.248	.770	47.119
16	17.000	16.400	.300	53.410	51.520	226.980	211.2400	15.7400	.225	.233	.680	52.890
17	18.000	17.320	.340	56.550	54.410	254.470	235.6100	18.8600	.212	.221	.610	63.370

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certain distance from the end, the standard taper being such that the pipe surface inclines toward the axis of the pipe by 1 in 32. This makes the total taper, as measured by the variation in outside diameter, equal to 1 in 16, or ¾ in. to the ft. The proportions of standard pipe threads and the standard dimensions of wrought-iron steam, gas, and water pipes are given in the accompanying tables

Pipe Measurements. — When taking measurements for piping, the center-to-center distances of the different pipe lines are measured first, and then allowance is made for the fittings.

In measuring for 45° fittings, as where offsets are required, place the fittings in position and measure between them, using try pieces that point straight toward each other. In case it is inconvenient to do this, the measurement representing the exact distance from center to center between the parallel pipe lines connected by the offset may be taken, and the length of the diagonal line from center to center of 45° fittings is found by multiplying the distance by 1.4142, and of 60° fittings by 1.1547. From the lengths thus found must be subtracted the distance between the ends of the diagonal pipe and the center of the fittings.

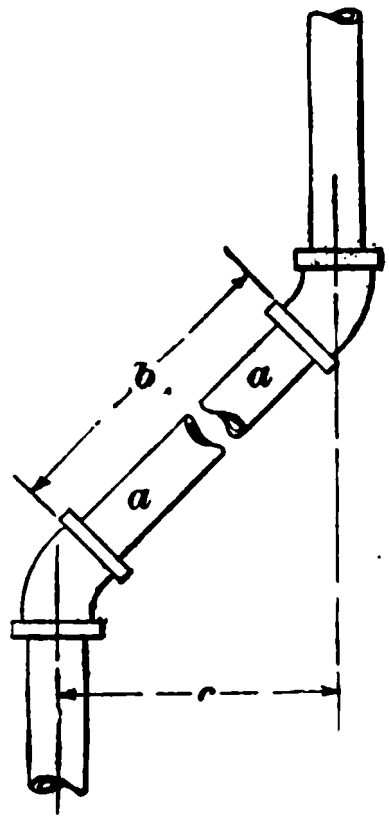

FIG. 1.

EXAMPLE.—What length of pipe is required at *b*, Fig. 1, assuming that 1 in. is allowed between each end of the pipe and the center of each fitting, the distance *c* being 4 ft. 9 in., and 45° fittings being used?

SOLUTION.—Multiplying 4 ft. 9 in., or 57 in., by 1.4142 and subtracting the sum of the distances from the end of the pipe to the center of the fittings at each end, we have $57 \times 1.4142 - (1 + 1) = 78.6$ in., or a trifle over 6 ft. 6½ in. Ans.

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A simple method for finding the diagonal length with 45° fittings is as follows: Strike two parallel chalk lines on the floor to represent the center lines of the pipes to be joined by the diagonal piece, as *a b* and *c d*, Fig. 2. Lay a steel square against one of these lines, as shown, and draw a perpendic

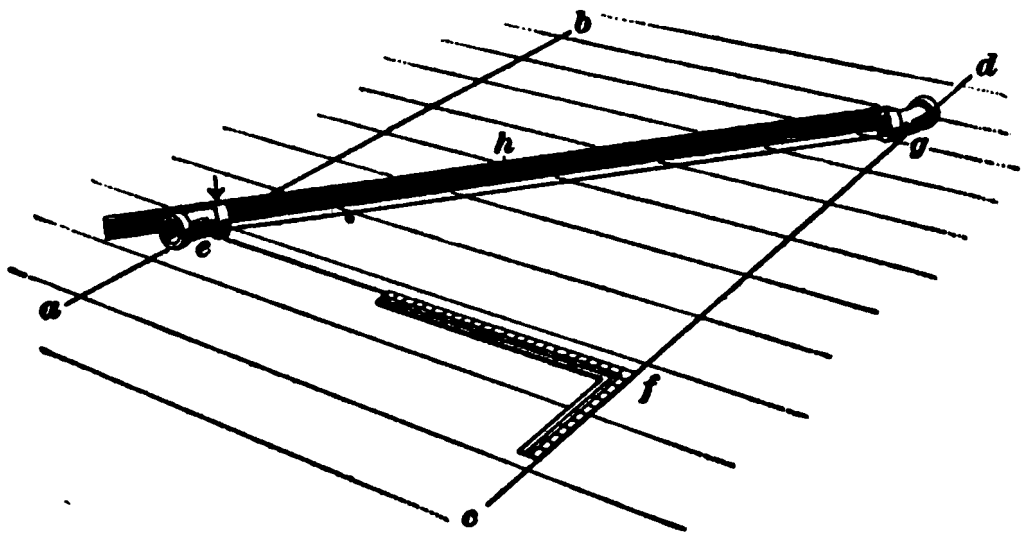

FIG. 2.

ular line *e f*. From the intersection at *f* on *c d* lay off a point *g*, making *f g* equal to *e f*. Draw a line through *e* and *g*. Then lay a 45° fitting over each of these intersections and measure with a rod *h* the length of pipe required.

SIZES OF PIPING.

General Rules.—The size of steam pipes for heating purposes depends on several factors, among which are the pressure, length of the pipe, and frictional resistance of the pipe and fittings. All these factors, including also the diameter of the pipe, influence the velocity of flow and hence the amount of steam delivered in a given time.

Steam-heating mains should be proportioned according to the desired drop in pressure and the amount of radiating surface to be supplied. As branches are taken off, the piping is commonly reduced in size toward the end of the main. Some pipe fitters reduce the size of mains in proportion to

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the decrease in the combined area of the branches to be supplied, but this is not correct. The reduction should be more gradual.

The frictional resistance to the flow of steam increases with the length of the pipe, the quantity of steam delivered being correspondingly diminished. Approximately, the resistance varies inversely as the square of the velocity; that is, taking a velocity of 100 ft. per sec. for example, and assuming the reduction in pressure in 100 ft. of main to be about 1½ lb., with 50 ft. velocity per sec. the reduction in pressure would be only one-fourth, or ⅜ lb.

In the design of large heating systems, it is essential that the length of the various pipes be considered in determining their diameter.

Empirical Rule for Ordinary Residence Mains.—Under the conditions ordinarily found in low-pressure, gravity, residence-heating systems, an adequate supply of steam can be obtained by allowing .8 sq. in. in sectional area of the main for each 100 sq. ft. of radiation to be supplied. This factor applies to mains larger than 2 in. and makes allowance for loss by condensation. For smaller mains, 1 sq. in. of sectional area should be allowed for each 100 sq. ft. of direct radiation.

Sizes of Mains for Two-Pipe Systems and Direct Radiation.—In the following table, prepared by Mr. A. R. Wolff, is given, for a two-pipe system, the amount of radiation that mains of different sizes and 100 ft. long will supply under different steam pressures. The values given are based on the assumption that 1 sq. ft. of radiating surface will transmit 250 B. T. U. per hr.; hence, the values in the columns headed "Total Heat Transmitted, B. T. U.," are obtained by multiplying by 250 the values in the columns headed "Direct Radiating Surface, Square Feet." The amount of radiation supplied by a pipe more than 100 ft. long may be found by multiplying the number of square feet of radiation given in the table, as corresponding to the size of the pipe, by the square root of the quotient obtained by dividing 100 by the length of the main, in feet. To avoid the necessity for calculating this factor, its

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value for mains of different lengths is given in table "Factors for Mains." To the actual length of the pipe must be added an allowance for the resistance of fittings, etc.; the corrected length is called the *equivalent length.* In low-pressure heating the resistance of bends and fittings is approximately equivalent to increasing the length of the main by the following amounts: Right-angle elbow, 40 diameters; globe valve, 125 diameters; entrance to T, 60 diameters. Thus, if a main 3 in. in diameter has an actual length of 124 ft., and three elbows, two globe valves, and one T, its equivalent length is $124 + 3 \times 40 \times \frac{3}{12} + 2 \times 125 \times \frac{3}{12} + 1 \times 60 \times \frac{3}{12} = 231.5$ ft.

SIZES OF MAINS, DIRECT RADIATION, TWO-PIPE SYSTEM.

Diameter of Supply, Inches. 100 Ft. Long.	Diameter of Return, Inches. 100 Ft. Long.	2 Lb. Pressure.		5 Lb. Pressure.	
		Total Heat Transmitted. B. T. U. Per Hour.	Direct Radiating Surface. Square Feet.	Total Heat Transmitted. B. T. U. Per Hour.	Direct Radiating Surface. Square Feet.
1	1	9,000	36	15,000	60
1¼	1	18,000	72	30,000	120
1½	1¼	30,000	120	50,000	200
2	1½	70,000	280	120,000	480
2½	2	132,000	528	220,000	880
3	2½	225,000	900	375,000	1,500
3½	2½	330,000	1,320	550,000	2,200
4	3	480,000	1,920	800,000	3,200
4½	3	690,000	2,760	1,150,000	4,600
5	3½	930,000	3,720	1,550,000	6,200
6	3½	1,500,000	6,000	2,500,000	10,000
7	4	2,250,000	9,000	3,750,000	15,000
8	4	3,200,000	12,800	5,400,000	21,600
9	4½	4,450,000	17,800	7,500,000	30,000
10	5	5,800,000	23,200	9,750,000	39,000
12	6	9,250,000	37,000	15,500,000	62,000
14	7	13,500,000	54,000	23,000,000	92,000
16	8	19,000,000	76,000	32,500,000	130,000

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FACTORS FOR MAINS.

Length of Pipe, Ft.	200	300	400	500	600	700	800	900	1,000
Factor	.71	.58	.5	.45	.41	.38	.35	.33	.32

Sizes of Mains for Indirect Radiation.—One square foot of indirect radiation will under natural draft condense as much steam as 2 sq. ft. of direct radiation. Therefore, the table, "Sizes of Mains, Direct Radiation, Two-Pipe System," may be used for determining the size of pipe required. To use the table for indirect radiation, multiply the given number of square feet of indirect radiation by 2; look for the number nearest to the product in the column headed "Direct Radiating Surface, Square Feet" and at the left the pipe sizes will be found.

Sizes of Mains for Direct-Indirect Radiation.—The sizes of mains for direct-indirect, also called semidirect, radiators can be found in the table headed "Sizes of Mains, Direct Radiation, Two-Pipe System," multiplying the given radiating surface by 1.5 before entering the column headed "Direct Radiating Surface, Square Feet."

Size of Main for One-Pipe Systems.—The pipe sizes given in the following table are such as will insure satisfactory results with single-pipe systems in which the distance of the water level in the return above the boiler water-line is from 6 to 12 in., the steam pressure varying from ¼ to 2½ lb. per sq. in.

Since in single-pipe work the steam and water of condensation flow through the same pipe, and frequently in opposite directions, it is necessary to use larger pipes than with two-pipe systems, so as to insure as free a flow of the opposing currents as practicable.

The pipe sizes given in the table "Size of Main, Direct Radiation, One-Pipe System," may be multiplied by .8 to obtain the diameter of supply mains for a two-pipe system. The corresponding diameter of return main may then be taken from the table "Sizes of Mains, Direct Radiation, Two-

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Pipe System." In applying both tables to the same two-pipe system a slight difference in the results may occur, because the tables represent the successful practice of different engineers rather than absolute values based on purely theoretical considerations. The differences that may be found are not material ones, however.

SIZE OF MAIN, DIRECT RADIATION, ONE-PIPE SYSTEM.

Radiating Surface. Square Feet.	Length of Main. Feet.								
	20	40	80	100	200	300	400	600	1,000
	Nominal Diameter of Pipe. Inches.								
20	1	1	1¼	1¼	1¼	1¼	1½	1½	1½
40	1¼	1¼	1¼	1¼	1½	1½	2	2	2
60	1¼	1¼	1½	1½	1½	1½	2	2	2½
80	1½	1½	1½	1½	2	2	2	2½	2½
100	1½	1½	1½	1½	2	2	2½	2½	3
200	2	2	2	2	2½	2½	3	3	3½
300	2	2	2	2	2½	2½	3	3	4
400	2	2	2½	2½	2½	3	3	3½	4
500	2½	2½	2½	3	3	3	3½	4	4½
600	2½	2½	2½	3	3	3½	3½	4	4½
800	2½	2½	3	3½	3½	3½	4	4½	5
1,000	3	3	3½	3½	4	4	4	4½	6
1,400	3	3	3½	4	4	4½	4½	5	6
1,800	3½	3½	4	4	4½	4½	5	5	7
2,000	3½	3½	4	4½	4½	5	5	6	7
3,000	4	4	4½	5	5	6	6	7	8
4,000	4½	4½	5	5	6	7	7	8	9
6,000	5	5	5	6	7	7	7	8	10
8,000	5	5	6	6	7	8	8	9	11
10,000	6	6	6	7	7	8	8	9	12
12,000	6	6	6	7	8	8	9	10	12
14,000	7	7	7	8	8	9	10	11	14
16,000	7	7	8	8	9	10	11	12	14
18,000	8	8	8	9	10	10	11	12	14
20,000	9	9	9	10	11	11	12	14	16

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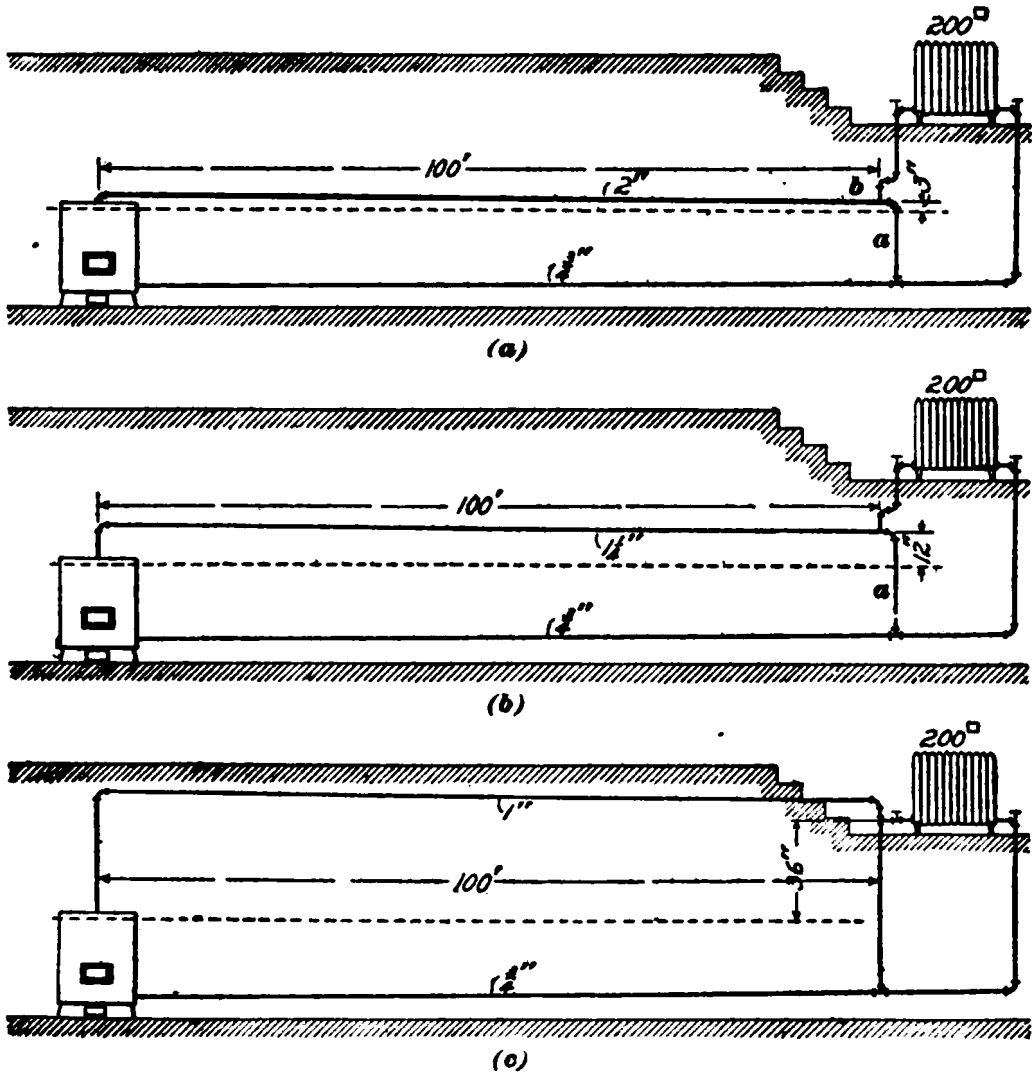
Influence of Available Drop in Pressure on Sizes of Mains.—The distance between the boiler water-line and the lowest point in the steam supply main often determines the size of pipe that must be used. To obtain satisfactory results the piping system must be designed according to the available drop in pressure. In operation, the height of the water level in the



returns above the water-line of the boiler represents the available drop in pressure, which is commonly expressed in inches of water column. Generally speaking, on gravity-return jobs, the higher the main the smaller it may be; and the nearer the lower end is to the level of the boiler water-line the larger must be the main. For instance, the above

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illustration shows how a radiator may be connected up with different sizes of pipe and yet the same heating results be obtained in each case under a 5-lb. pressure. At (*a*), the main has been run so low that it is necessary to use a 2-in. main to prevent such a drop in pressure as would cause the water in the drip *a* to rise into the main and thereby flood the inlet to the pipe *b*. The end of the main is only 3 in. above the boiler water-line, shown dotted, making necessary the use of a large main.

At (*b*), the available height to which the water in *a* may rise is 12 in. This is due simply to raising the main. A 1¼-in. main will then serve the radiator as easily as the 2-in. main in (*a*).

The main shown at (*c*) is raised to a height of 36 in. above the boiler water-line, and a 1-in. pipe will serve the radiator as easily as the larger pipes required under the conditions indicated in (*a*) and (*b*). The only difference is that a pressure of about 5 lb. may be carried in (*c*) and about 4 lb. in (*b*), while (*a*) will work satisfactorily at a pressure of 1 lb., provided, of course, that in each case the boiler water-line does not rise above the dotted line shown. This shows how heating engineers may use small pipes on some jobs, but must use large pipes on others. It shows, too, how economy may be exercised in piping a steam job. There are many places where the fitter may reduce the sizes of the pipes by raising them, but he must use good judgment, otherwise there will be times when the water will back up in the mains and cause considerable trouble. The pipe sizes given in the illustration are the smallest that should be used. To provide a margin of safety, it is advisable to make all the pipes one size larger than shown. This will provide for the increased flow of steam when it is turned on a cold radiator.

The factors given in the accompanying table may be used in calculating the size of piping for various pressure drops in mains 100 ft. long. They represent values obtained by Prof. R. C. Carpenter and are applicable to ordinary house-heating installations, where the amount of radiation does not exceed 2,000 sq. ft.

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FACTORS FOR BASING SIZES OF MAINS ON AVAILABLE DROPS.

Available Drop in Pressure. Inches of Water.	To Find Area of Steam Main in Square Inches, Multiply Each 100 Sq. Ft. Radiating Surface by		Required Steam Pressure. Pounds.
	For One-Pipe System.	For Two-Pipe System.	
2.0	1.35	.900	1 to 2
6.0	1.01	.675	2 to 3
8.0	.67	.450	3 to 4
12.6	.56	.375	4 to 5
18.0	.45	.300	5 to 6

Sizes of Returns.—The sizes of return pipes depend on the size of the system and the character of the returns, whether wet or dry. With *wet returns*, it is considered good practice to make the area of the return piping equal to about one-fourth of that of the steam piping in plants where the steam pipe is larger than 3 in. Where the steam pipe is less than 3 in. it is customary to make the return one or two sizes smaller than the corresponding steam pipe.

With *dry returns*, it is considered good practice to make the area of the piping equal to about one-half that of the corresponding steam pipe. It is good practice never to use a return smaller than ¾-in. pipe. The table, "Sizes of Mains, Direct Radiation, Two-Pipe System," previously given, indicates sizes of return pipes, with corresponding steam mains, that have been found to work satisfactorily in practice. The diameter of return pipes from indirect heating surfaces should be about 50 per cent. greater than for a similar amount of direct radiation.

Sizes of Drip Pipes for Steam Mains.—Since the amount of water of condensation to be handled by drip or relief pipes is practically an unknown quantity, no general rule can be given for proportioning them. It has been found in practice,

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however, that the sizes given in the accompanying table are ordinarily ample for draining covered mains of various lengths. Drip pipes should be connected to the return main in such a manner as not to impede the circulation, but rather to increase the velocity with which the water of condensation returns to the boiler.

SIZES OF DRIP PIPES FOR COVERED STEAM MAINS.

Diameter of Steam Main. Inches.	Length of Steam Main. Feet.					
	100	200	400	600	800	1,000
	Diameter of Drip Pipe. Inches.					
Up to 2	¾	¾	¾	¾	1	1¼
3	¾	¾	¾	1	1¼	1¼
4	¾	¾	1	1¼	1¼	1½
5	¾	¾	1	1¼	1½	1½
6	¾	1	1¼	1½	1½	2
7	1	1	1¼	1½	2	2
8	1	1	1¼	1½	2	2½
9	1	1¼	1½	2	2½	2½
10	1¼	1¼	1½	2	2½	3
11	1¼	1¼	1½	2	2½	3
12	1¼	1¼	1½	2½	3	3½
14	1½	1½	2	2½	3	4
16	1½	2	2½	3	3½	4

Sizes of Drip Pipes for Risers.—The sizes of drip pipes at the foot of risers of one-pipe systems depend on the amount of radiation supplied from the risers. Ordinarily the sizes given for return pipes in the second column from the left in the table "Sizes of Mains, Direct Radiation, Two-Pipe System," previously given, are suitable and will give satisfactory results by using them in conjunction with the figures given in the radiation column under the 5-lb. pressure. If the drips are connected to a dry-return main without being sealed, steam will flow through them into the return main and may cause water hammer.

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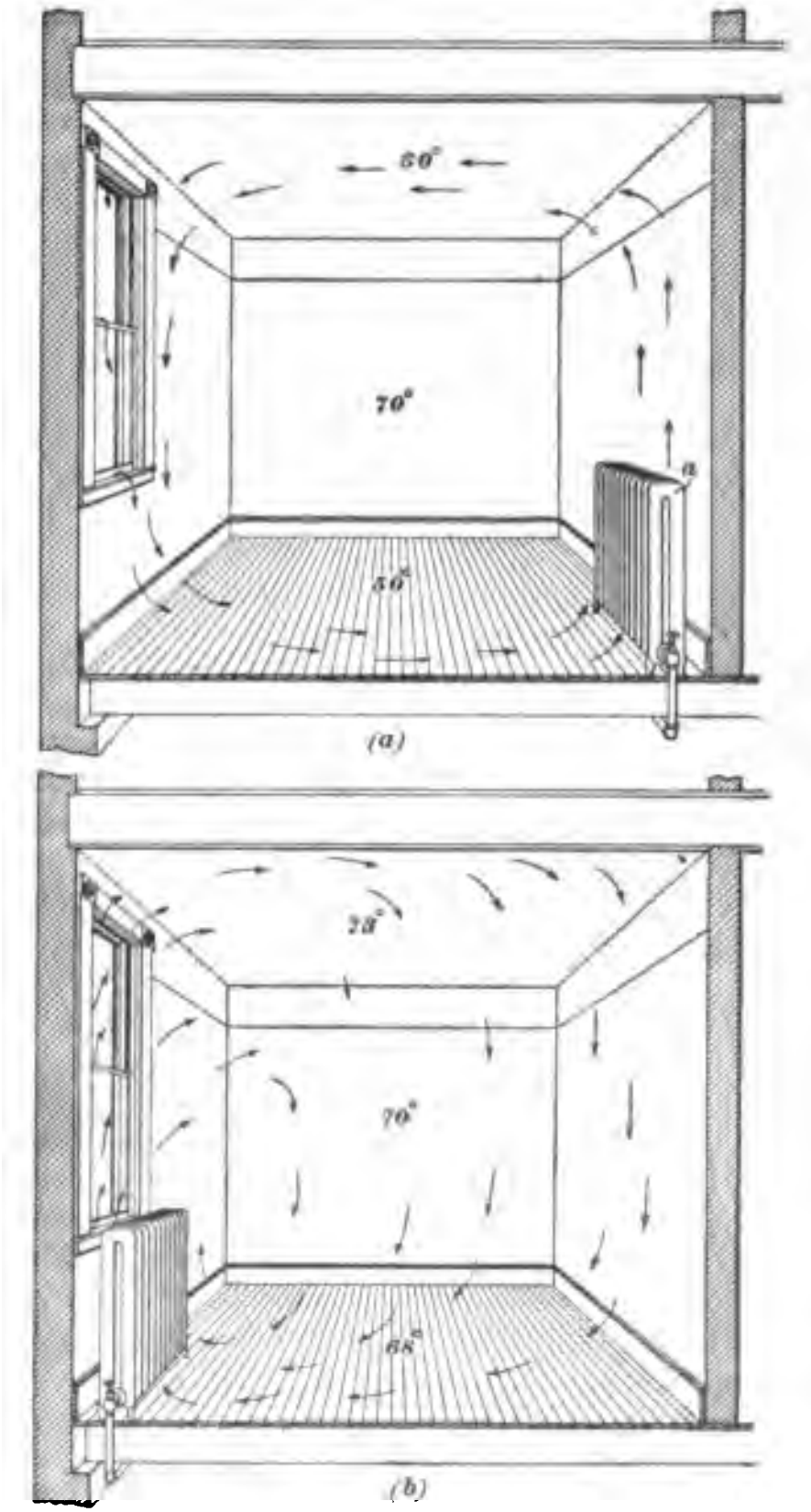

FIG. 1.

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RADIATION.

Location of Radiators.—Direct radiators should be located near the outer walls, where the cooling influence is greatest. When the radiators are so located that the warm-air currents ascending from them will mix with the incoming cold-air leakage, a nearly uniform temperature will be maintained throughout the room.

Fig. 1 serves to illustrate the difference in heating results between placing a radiator under the window, and placing it against an inner wall. The arrows show the circulation of the air.

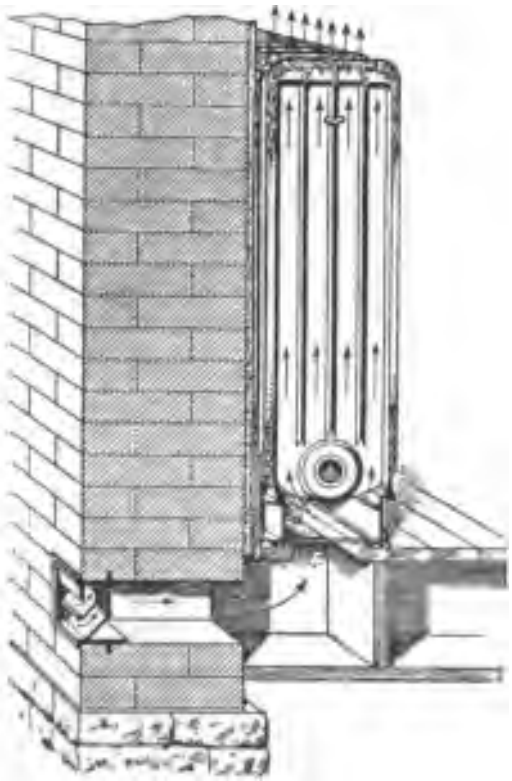

FIG. 2.

Direct-indirect radiators are necessarily placed against the outer walls, as shown in Fig. 2, and as a rule are thereby located properly.

Indirect radiators are usually located against or near outer walls, as shown in Fig. 3. The efficiency of the radiator increases with the height of the radiator flue.

In factories and workshops heated by steam in pipe coils, it is customary to place the coils on the walls of the room and near the floor. Another common plan is to place the coils overhead, suspending them horizontally below the ceiling. The movement of machinery will usually diffuse the heated air throughout the apartment in a satisfactory manner.

Proportioning Radiation.—To find the amount of direct radiating surface required to heat a room, basing calculations on its cubic contents, allow 1 sq. ft. direct radiating surface to the number of cubic feet shown in the following table:

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PROPORTION OF RADIATING SURFACE TO VOLUME OF ROOM.

Description.	Cu. Ft.
Bathrooms or living rooms, with 2 or 3 exposures and large amount of glass surface	40
Living rooms, 1 or 2 exposures with large amount of glass surface	50
Sleeping rooms	55– 70
Halls	50– 70
Schoolrooms	60– 80
Large churches and auditoriums	65–100
Lofts, workshops, and factories	75–150

The above ratios will give reasonably good results on ordinary work, if the engineer uses proper judgment in allowing for exposures, leakages through building, etc.

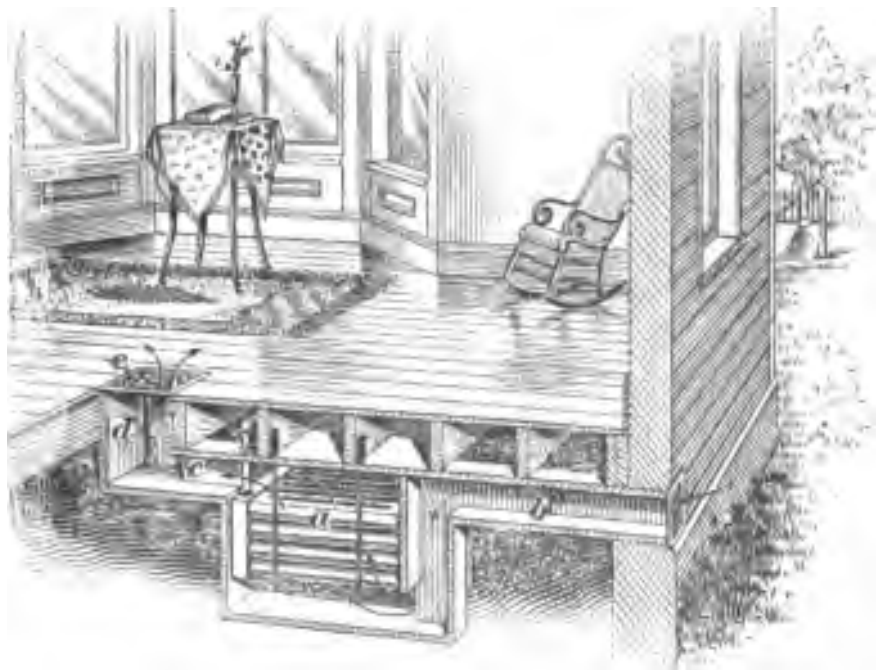

FIG. 3.

This table applies to direct radiation only. If indirect radiators are used, allow not less than 50 per cent. more surface. If direct-indirect radiators are used, allow not less

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than 25 per cent. more surface. The general use of any method of proportioning radiation to the cubical contents of the rooms to be heated is not advisable. The foregoing table is presented merely for the convenience of those who may be able to use it with good judgment, and for "checking up" purposes.

Proportion of Radiating Surface to Glass Surface Baldwin's Rule.—*Divide the difference in temperature between that at which the room is to be kept and the coldest outside atmosphere, by the difference between the temperature of the steam pipes and that at which the room is to be kept. The quotient will be the square feet or fraction thereof of plate or pipe surface to each square foot of glass, or its equivalent in wall surface.*

Let S = amount of radiating surface required to counteract cooling effect of glass and its equivalent in exposed wall surface, in square feet;

t = difference, in degrees F., between desired temperature of room and that of external air;

t_1 = difference, in degrees F., between temperature of heating surface and that of air in room;

s = number of square feet of glass and its equivalent in exposed wall surface.

Then,
$$S = \frac{t}{t_1} s.$$

The heating surface found by this rule only compensates for the heat lost by transmission through windows, walls, and other cooling surfaces; it does not provide for cold air entering the room through loosely fitting doors, windows, etc., for which an ample allowance must be made. Some buildings are so poorly constructed that 50 per cent. or more must be added to the amount of heating surface obtained by the rule in order to counteract the cooling effect of these air leakages. A common practice is to add 25 per cent. for buildings of ordinary good construction. Ample allowance should be made for rooms exposed to cold winds. This rule also applies to hot-water heating.

Suppose that we have three rooms A, B, and C, as shown in the accompanying illustration, of precisely the same

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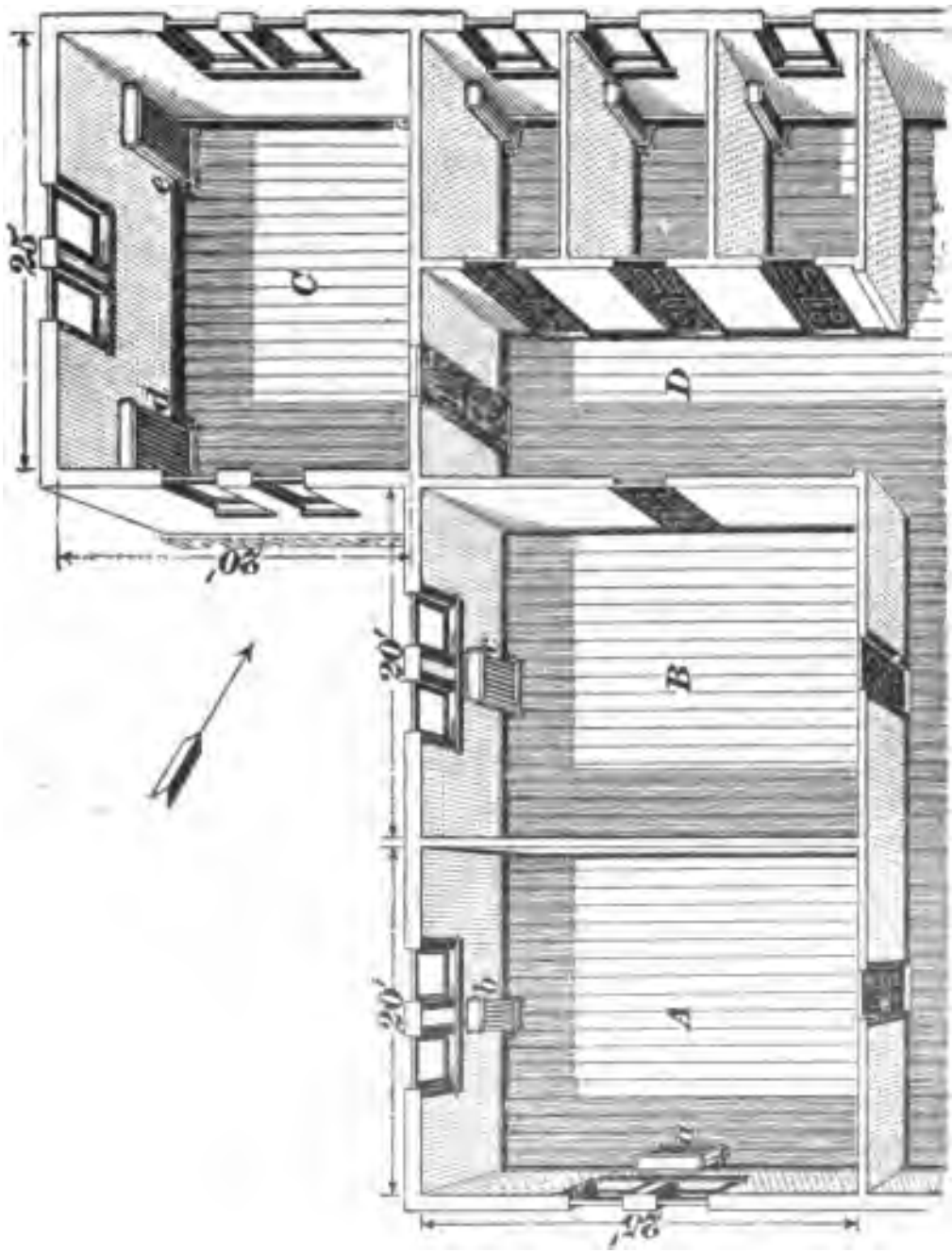
dimensions, and consequently having the same cubical contents, the rooms being each 25 ft. long by 20 ft. wide, with a 10-ft. ceiling. Let us also suppose that the halls, or corridors, *D* and



the other rooms in the building will be warmed to a temperature equal to that desired in *A*, *B*, and *C* by radiators not shown; first proceed to find, by Baldwin's rule, the

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amount of heating surface required to maintain a temperature of 70° F. in *A*, *B*, and *C*, assuming that the radiators will be heated by steam having a pressure of 5 lb. by the gauge, the outside temperature being 10° below zero. Let us suppose that the windows are each 6 ft. by 3 ft. and that the exposed walls are built of good, ordinary brick, lathed and plastered inside.

When lathed and plastered brick walls are used, as in the figure it is safe to estimate that about 10 sq. ft. of wall surface will be equivalent in cooling power to 1 sq. ft. of glass; consequently, in this case

$$\frac{\text{wall surface}}{10} = \text{equivalent glass surface.}$$

Let us commence with room *A*; the amount of glass surface here is $6 \times 3 \times 4 = 72$ sq. ft. To this must be added the exposed wall surface reduced to a glass equivalent; thus,

$$\frac{10\,(25 + 20) - 72}{10} = 37.8 \text{ sq. ft.}$$

Since we assume that the inner walls, floors, and ceilings are not cooling surfaces, the total cooling surface of the room *A* is $72 + 37.8 = 109.8$ sq. ft. $= s$.

The temperature of steam at 5 lb. gauge pressure is 227°, and the difference between 70° above zero and 10° below zero is 70° + 10°; therefore, substituting in the formula, we have

$$S = \frac{70 + 10}{227 - 70} \times 109.8 = 56 \text{ sq. ft.; nearly.}$$

This, however, counteracts only the cooling effect of the walls and windows, and to make reasonable allowance for air leakage, add 25 per cent. of the above amount, or 14 sq. ft., which gives $56 + 14 = 70$ sq. ft. of direct radiating surface.

Suppose that we allow 20 per cent. of the direct radiating surface (70 sq. ft. in this case) for a moderate exposure to winds; the size of the radiator we would place in *A* would then be 70 + 14, or 84 sq. ft.

For convenience, we may divide this into two radiators, *a* and *b*, *a* having an area of 56 sq. ft. and *b* an area of 28 sq. ft. This will so divide the radiator surface that one-third,

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or 28 sq. ft., may be used during mild weather; two-thirds, or 56 sq. ft., for moderate cold weather; and the whole, or 84 sq. ft., for use during severe weather.

In like manner and under the same conditions, we find, for the room *C*, that the sizes of the radiators *c*, *d*, and *e* should be, respectively, 40, 82, and 42 sq. ft.

As the coldest winds blow in the direction of the arrow, the radiator having 82 sq. ft. is placed in the left-hand exposed corner of the room *C*. A better distribution of the radiating surface in this room would be to make *d* 42 sq. ft. only and place a radiator having 40 sq. ft. between the windows toward which the arrow points; this would insure a more uniform temperature in the room.

It will be observed that *A*, *B*, and *C*, three rooms having the same shape and cubical contents require 84, 40, and 124 sq. ft. of heating surface, respectively, in order to maintain a temperature of 70° F. in each when the outer atmosphere is 10° below zero. This example shows how imperfect must be the rule-of-thumb method of proportioning radiators to the cubical contents of rooms.

Tables Useful in Radiator Installation.—A number of tables that will prove of use in proportioning radiation for various purposes are given in the succeeding pages.

SIZES OF TAPPINGS FOR PRIME SURFACE RADIATORS.

Direct Radiators.					Indirect Radiators.		
1-Pipe Work.		2-Pipe Work.					
Surface. Sq. Ft.	Size. In.	Surface. Sq. Ft.	Steam. In.	Return. In.	Surface. Sq. Ft.	Steam. In.	Ret. In.
25	1	30	¾	¾	30	1	¾
25– 50	1¼	30– 50	1	¾	30– 50	1¼	1
50– 90	1½	50–100	1¼	1	50–100	1½	1¼
100–160	2	100–160	1½	1¼	100–160	2	1½

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DIRECT RADIATORS.

Heat units emitted per hour, per square foot of external surface, per degree of difference in temperature.

VERTICAL TUBES, PRIME SURFACE RADIATORS.

Difference in Temperature. F°.	Tubes Massed.		Single Row Tubes.	
	Height, 40 In. B. T. U.	Height, 24 In. B. T. U.	Height, 40 In. B. T. U.	Height, 24 In. B. T. U.
50	1.29	1.54	1.46	2.01
60	1.33	1.58	1.50	2.06
70	1.36	1.62	1.54	2.12
80	1.39	1.66	1.58	2.17
90	1.41	1.70	1.62	2.22
100	1.46	1.74	1.65	2.27
110	1.49	1.78	1.69	2.32
120	1.52	1.82	1.73	2.38
130	1.56	1.86	1.77	2.43
140	1.59	1.90	1.81	2.48
150	1.63	1.94	1.85	2.53
160	1.66	1.98	1.88	2.59
170	1.69	2.02	1.92	2.64
180	1.73	2.06	1.96	2.70
190	1.76	2.10	2.00	2.75
200	1.80	2.14	2.03	2.80
210	1.83	2.18	2.07	2.85
220	1.86	2.22	2.11	2.90
230	1.90	2.27	2.15	2.96
240	1.93	2.31	2.19	3.01

FLUE RADIATORS, NATURAL DRAFT.

Radiating Surface.		B. T. U. Emitted.		Total B. T. U. Emitted.	
Extended. Sq. Ft.	Plain. Sq. Ft.	Extended. Sq. Ft.	Plain. Sq. Ft.	Extended.	Plain.
57.80	40.40	1.65	1.97	95.37	79.58
6.40	4.24	2.05	2.39	13.12	10.13
63.10	41.20	1.39	1.85	87.81	76.22
7.18	4.50	1.90	2.24	13.64	10.08

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INDIRECT RADIATORS.

Heat units emitted per square foot of actual surface per hour, per degree of difference in temperature.

NATURAL DRAFT, EXTENDED SURFACES.

Height of Flue. Feet.	Velocity of Air per Second. Feet.	B. T. U. Emitted.	Height of Flue. Feet.	Velocity of Air per Second. Feet.	B. T. U. Emitted.
5	2.90	1.70	30	6.70	2.60
10	4.10	2.00	35	7.14	2.67
15	5.00	2.22	40	7.50	2.72
20	5.70	2.38	45	7.90	2.76
25	6.30	2.52	50	8.20	2.80

FORCED DRAFT, PLAIN SURFACES.

Velocity of Air per Second. Feet.	B. T. U. Emitted.	Velocity of Air per Second. Feet.	B. T. U. Emitted.	Velocity of Air per Second. Feet.	B. T. U. Emitted.
3	3.42	8	5.71	18	8.50
4	4.00	10	6.33	20	9.00
5	4.50	12	6.93	22	9.42
6	4.94	14	7.50	24	9.79
7	5.33	16	8.06		

Extended-surface indirect radiators are frequently used for small installations of a blower heating system, but their efficiency is not nearly as high as that of pipe heaters. When extended-surface indirect radiators are thus used, the surface should about be doubled, and the sections must be staggered. Extended-surface indirect cast-iron radiators are used extensively for gravity air circulation, being supplied with a cold-air duct to the outer atmosphere and a warm-air pipe to a register in the room to be warmed. Both the plain-surface indirect and the pipe heaters are used extensively for blower systems of heating. They are usually set about 16 to 24 pipes deep, and are supplied with exhaust steam from engines, or live steam through a pressure regulator.

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APPROXIMATE AMOUNT OF RADIATING SURFACE REQUIRED FOR HEATING GREEN HOUSES BY STEAM.*

OUTDOOR TEMPERATURE, 10° F. BELOW ZERO.

Glass Surface. Square Feet.	Temperature Maintained. Degrees Fahrenheit.				
	50	60	70	80	90
	Radiation Required.				
100	16	22	28	34	40
200	32	44	56	68	80
400	64	88	112	136	160
600	96	132	168	204	240
800	128	176	224	272	320
1,000	160	222	280	340	400
1,500	240	333	420	510	600
2,000	320	444	560	680	800
3,000	480	666	840	1,020	1,200
4,000	640	888	1,120	1,360	1,600
5,000	800	1,110	1,400	1,700	2,000
7,500	1,200	1,665	2,000	2,550	3,000
10,000	1,600	2,222	2,800	3,400	4,000

* For heating by hot water, the required amount of radiating surface may be found by multiplying the values above tabulated by 1.5.

TESTING HEATING SYSTEMS.

The following table will be found useful in determining at any time whether a given heating apparatus is capable of maintaining a temperature of 70° throughout the building in zero weather. As an illustration, suppose the outdoor temperature to be 50° at the time of testing; then, if the temperature within the rooms is equal to or in excess of 99° F., as given by the table for such condition it may safely be assumed that sufficient heating surface has been provided

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to heat the rooms to a temperature of 70° F. in zero weather, the force and direction of the wind being the same as on the day of testing.

TEMPERATURES OBTAINED WITH STEAM AT 3-LB. PRESSURE.

Temperature Outside Air. Degrees Fahrenheit.	Heat Emitted per Sq. Ft. per Hr. per Deg. Difference in Temp. B. T. U.	Total Heat Emitted per Sq. Ft. per Hr. B. T. U.	Temperature of Room. Degrees Fahrenheit.	Difference in Temp. Between Steam and Air in Room. Degrees Fahrenheit.
— 10	1.96	300	67	153
0	1.87	281	70	150
10	1.80	263	74	146
20	1.75	245	80	140
30	1.69	227	86	134
40	1.66	211	93	127
50	1.62	196	99	121
60	1.55	179	105	115
70	1.50	164	111	109
80	1.44	148	117	103
90	1.40	136	123	97
100	1.35	122	130	90

EXHAUST AND VACUUM HEATING SYSTEMS.

Exhaust System.—The *exhaust steam-heating system* is a low-pressure system that is provided with special apparatus that adapts it to receive the exhaust steam from engines and pumps, thereby saving the heat in exhaust steam that would otherwise go to waste.

The general arrangement of apparatus for controlling the steam supply and drainage in an exhaust system is shown in the accompanying illustration. The steam main *a* is connected to the exhaust pipe *b* and also to a pipe *c* that supplies live steam from the boilers. This steam passes through a pressure-reducing valve *e* and is lowered in pressure to the desired amount before entering the heating main. By this

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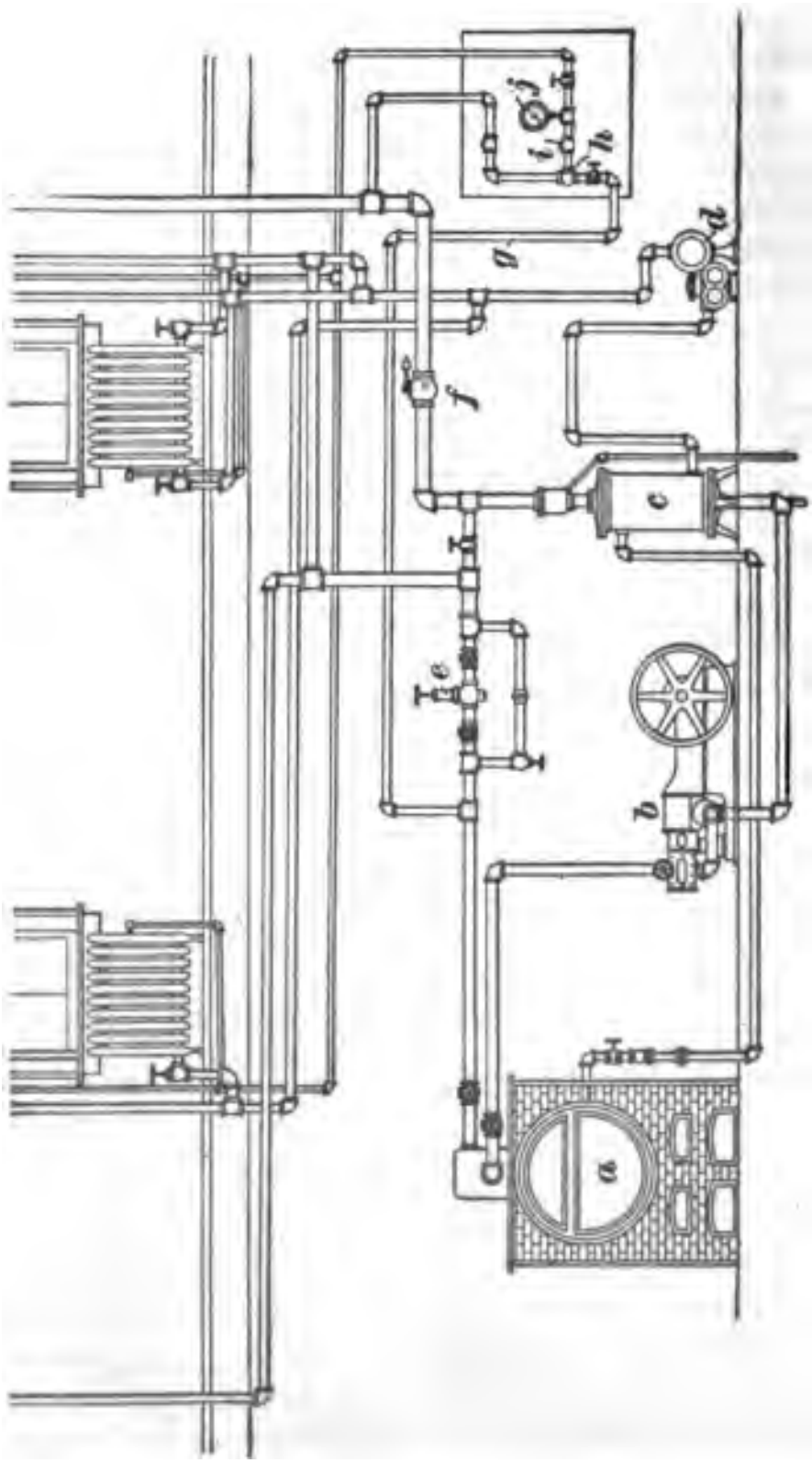

FIG. 2.

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Paul System.—What is known as the *Paul system* of heating is illustrated in Fig. 2. The general arrangement of the mains in the basement is similar to that of the systems described. From the boiler *a* steam is supplied to the engine *b*, from which the exhaust passes to the feedwater heater *c* and thence to the heating system, the feed-pump *d* returning the water of condensation to the boiler. A by-passed reducing valve *e* in the supplementary live-steam connection controls the supply of steam from the boiler in making up for any deficiency in the available amount of exhaust steam. The escape pipe to the roof is provided with a lightly weighted back-pressure valve *f*. The return pipe is connected to an automatic pump governor. The steam pipe *g* connects to the exhausting apparatus *h*, the discharge pipe from which is connected to the exhaust escape pipe to the atmosphere. The air pipes are connected to the suction opening in the exhausting apparatus *h* and have a check-valve *i* that serves to hold the vacuum in the air pipe, a gauge *j* indicating the amount of vacuum obtained. The exhausting apparatus and connections are auxiliary to regular gravity steam-heating systems to which the apparatus is commonly applied. The radiators may be arranged on the one-pipe, down-feed system, or may be connected up on the two-pipe, up-feed system. The system of steam and return pipes is practically the same, as far as the risers and connections to the radiators and mains are concerned, as for ordinary gravity systems. The air piping is practically the same as would be erected for gravity systems, with the exception that in the cellar the air pipe is connected to the exhausting apparatus of the system.

In Fig. 3 is shown the exhausting apparatus for a plant having a large number of radiators, the apparatus being arranged in duplicate so that either ejector may be operated should the other become disarranged. Live steam enters the exhausting apparatus through the pipe *a* and one or both of the valves *b*, *b*, passing to the ejectors *c*, *c*, pipes *d*, *d*, check-valves *e*, *e*, and through *f* to the exhaust escape pipe. The flow of steam through the ejectors *c*, *c* creates a partial vacuum in the air-line piping *g*, *g*, through which the air is

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drawn from the radiators. The valves *h*, *h* provide for the independent operation of either half of the apparatus, while the check-valves *i*, *i* serve to prevent the establishment of a pressure in the air piping equal to or greater than that of

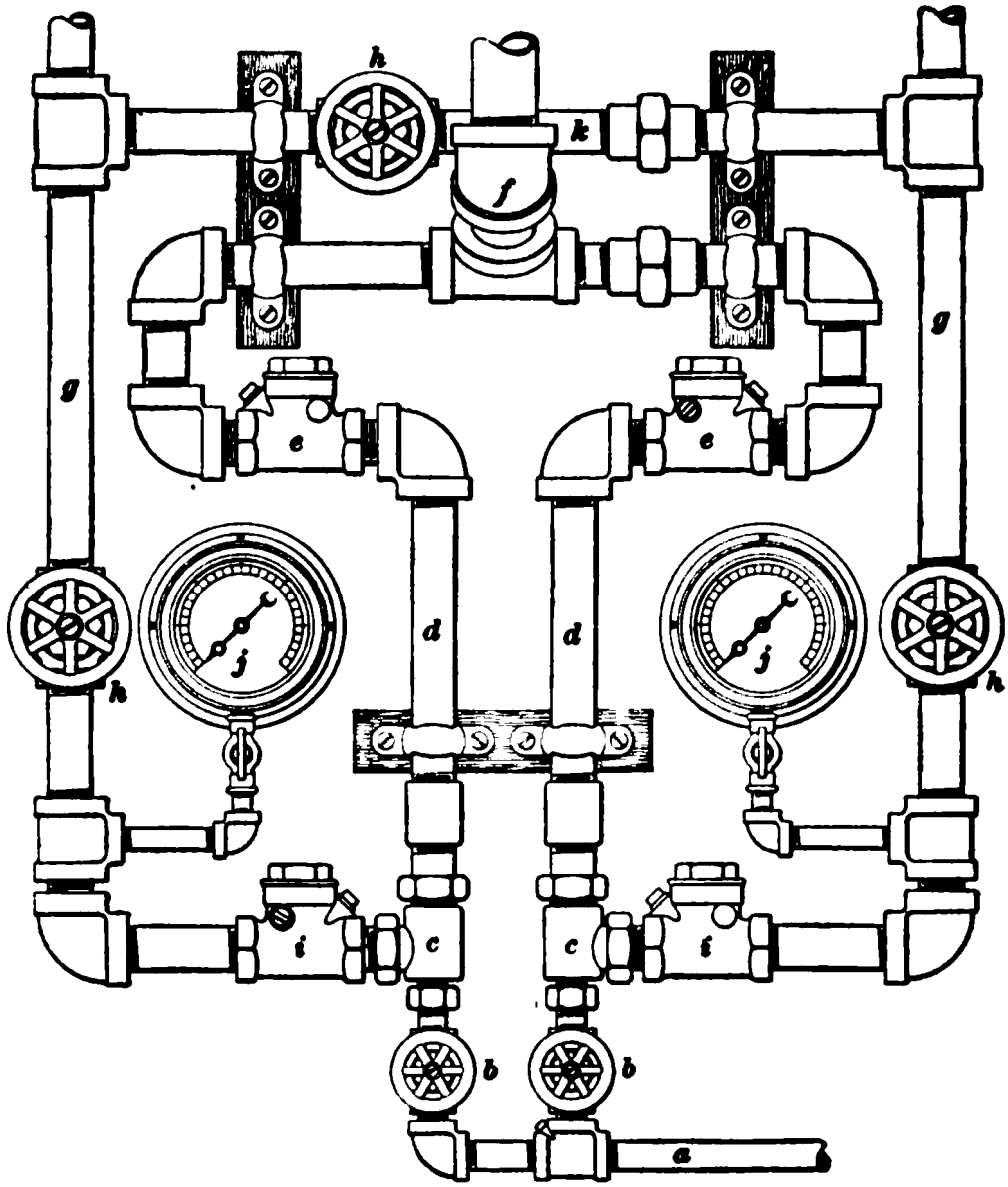

FIG. 3.

the atmosphere. The vacuum gauges *j*, *j* indicate the extent of the vacuum created by the steam in flowing through the ejectors *c*, *c*. The pipe *k* serves as a by-pass, by which one ejector may temporarily remove air from both air lines.

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Mercury-Seal System.—The Trane system of vacuum heating belongs to a class of heating systems in which a partial vacuum created by condensation is maintained by a sealing device that prevents the entrance of air to the piping. In this system the main air pipe is connected to the top of a mercury sealing device. Automatic operation of the apparatus is obtained by using a thermostat in connection with a diaphragm draft regulator on the boiler. The weight on the diaphragm regulator is adjusted to the requirements of the weather. Immediately on the air reaching the desired temperature, the thermostat closes the necessary electrical circuits for actuating the motor with which the thermostat and lever of the diaphragm regulator are connected. Thereupon the motor closes the drafts, and the thermostat assumes control of the fire, continuing in control until the temperature of the steam becomes too low to supply sufficient heat to maintain the required temperature in the room, when the thermostat transfers the control of the fire to the diaphragm regulator. By the joint action of the thermostat and diaphragm regulator, the steam pressure expels the air and the condensation of steam creates the partial vacuum wherewith the circulation of steam thereafter takes place.

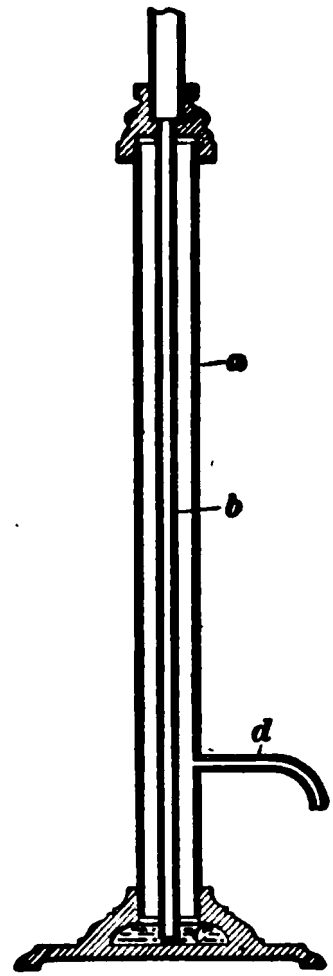

FIG. 4.

The mercury trap, shown in Fig. 4, consists of an outer tube *a* and an inner tube *b* through which air from the heating system discharges through the mercury *c*. As long as the air pipe is cold and there is pressure above that of the atmosphere to drive the air from the system, it will be forced through the mercury and out of the orifice *d* in the side near the base of the seal. The use of

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the mercury seal in connection with a low-pressure steam apparatus converts the latter into a vacuum heating system.

Each radiator is provided with a thermostatic air valve, such as is used with the Paul system, and as the air cannot return to the radiators because of the mercury seal, the steam may be maintained at a lower temperature than 212° owing to the absence of air and the partial vacuum throughout the system due to condensation.

The sizes of air mains required are ⅛ in. for 500 ft. of radiation, ¼ in. for 1,000 to 2,000 ft. of radiation, 1 in. for 3,000 ft. of radiation. The air pipe risers are ⅛ in. to ¼ in., ordinarily.

In order to maintain the vacuum created by condensation, it is necessary that the valves and all joints shall be absolutely tight; and since the ordinary types of radiator valve with packed stuffingbox leak sufficiently to destroy the vacuum, it is desirable to use a special type of steam valve in which entrance of air to the piping system is prevented by substituting a flexible diaphragm for the ordinary stuffingbox.

CENTRAL STATION OR DISTRICT HEATING SYSTEM.

What is known as the *district system* of steam heating is employed in towns and cities, the steam being distributed from a central station by means of underground mains laid through the streets. A common arrangement of the connections from the street mains to the house pipes is shown in the accompanying illustration. The service pipe *a* is provided with a valve *b* inside the basement wall, so that the house system may be shut off when desired. The steam passes through a pressure-reducing valve *c* and thence into the distributing pipe or house main *e*. The water that may enter from the service pipe is led away by the drain pipe *d*. The returns are all connected into the return main *f*, which is below the water level fixed by the elevation given the steam trap *t*; thus, in the figure, it is at the line *g*. The hot water from the trap should never be discharged directly into the house drains, because of its destructive effect on the pipes, but should be cooled before escaping to the sewers, by allow-

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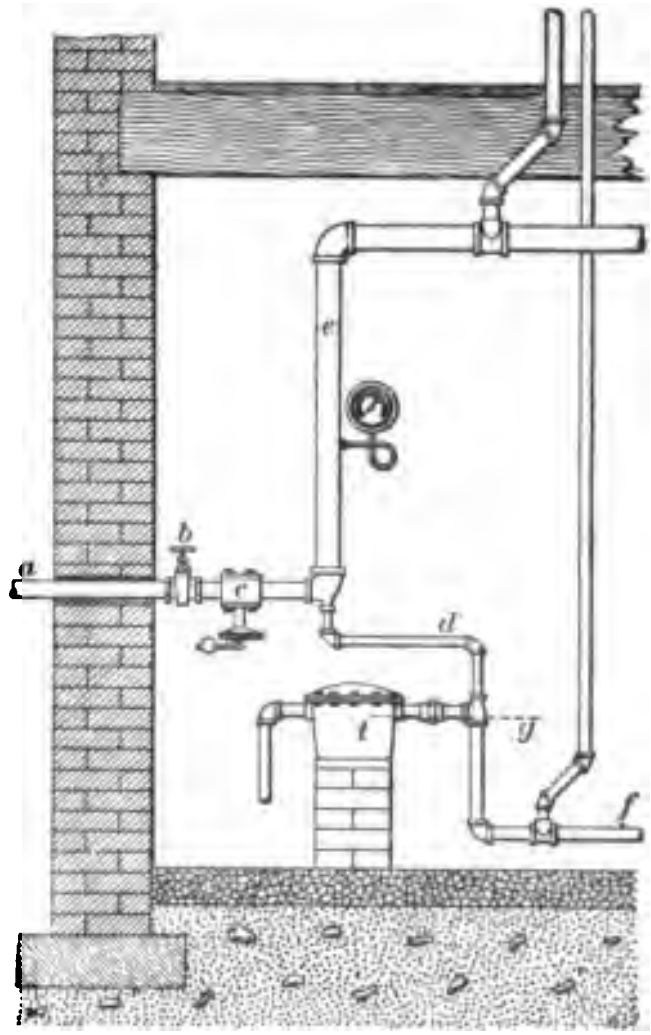
ing it to flow through a coil of pipes called a *cooling coil.* The coil should never deliver directly into the drainage system, but in all cases should deliver into a deep, sealed trap. This is to prevent drain air entering the heating system or the building. The trap, or hotwell, should always deliver into the house-sewer connection on the sewer side of the main-drain trap, to prevent hot vapors passing up the iron drainage system in the building.



The size of cooling coil, in square feet, may be determined closely by means of the factors given in the accompanying table, "Cooling-Coil Factors." The usual size of trap can be found from the table, "Capacities of Steam Traps," which gives the approximate amounts of heating surface, in square feet, from which the trap will readily discharge the water of condensation. The inlet and outlet tappings indicate the size of the trap.

COOLING-COIL FACTORS.

Temperature of Water Discharged by Trap. Degrees F.	For Size of Cooling Coil Multiply Radiating Surface by
160	.050
140	.066
120	.084
100	.100

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CAPACITIES OF STEAM TRAPS.

Size of Trap.			Capacity of Trap.			
Type of Trap.	Inlet. Inches.	Outlet. Inches.	Direct Radiation. Sq. Ft.	Indirect Radiation. Sq. Ft.	Hot-Blast Heater. Sq. Ft.	Tempering Coils. (4 Rows) Sq. Ft.
Bucket.	¾	¾	1,500	1,000	250	125
	1	1	2,250	1,500	375	200
	1¼	1¼	3,600	2,400	600	300
	1½	1½	6,000	4,000	1,000	500
Expansion.	1	½	1,166	800	200	100
	1¼	¾	2,500	1,660	415	200
	1½	¾	5,000	3,320	830	415
	1½	1	10,000	6,660	1,666	500
Float.	¾	¾	2,400	1,600	400	100
	1	1	4,500	3,000	750	375
	1¼	1¼	6,000	4,000	1,000	500
	1½	1½	7,500	5,000	1,250	850

DRYING BY STEAM.

Methods.—There are four common methods of drying by steam. First, by bringing the materials to be dried into contact with revolving, polished, steam-heated cylinders. Second, by placing the materials in drying closets heated by high-pressure or low-pressure steam circulating through coils of pipes, the air in the drying room only moving by the force of gravity. Third, by placing the materials in steam-heated drying closets having one or more horizontal disk fans near the ceiling of the drying chamber to agitate the air therein. Fourth, by placing the materials in drying closets and evaporating the moisture by means of large quantities of air forced over the pipe coils and through the drying room by means of a fan. A fifth method involves the use of a condenser through which the moisture-laden air is passed to

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lower its temperature and remove part of its moisture, the air thus treated being circulated over and over between the drying closet and the condenser compartment by means of a fan.

Drying by Evaporation.—If a body of warm air, of ordinary pressure and humidity, be brought into contact with water, evaporation will begin at once. The vaporization of the water will continue until the air attains the maximum percentage of humidity, or becomes *saturated*. The rapidity of evaporation will be proportional to the difference between the actual humidity of the air and the possible humidity, or the point of maximum saturation.

The capacity of air for absorbing moisture depends on its temperature and its relative humidity. The higher its temperature and the lower its percentage of humidity, the greater will be the quantity of moisture it can absorb. Should the air be cooled after becoming saturated, part of the moisture will be deposited in the form of fog, which will condense into dew on any object colder than the air. If the temperature of the air is again raised, the air will take up more moisture, which will again be deposited in the form of dew when the temperature falls. It is this moisture-absorbing property of air that makes air valuable as a drying medium. The efficiency of a drying apparatus in which hot air is used as the drying agent depends on several factors, among which are the following:

First, the amount of moisture in the air before it is heated; second, the temperature imparted to the air; third, the amount of surface of wet material from which evaporation can readily take place; fourth, the volume of air circulated through the dryer; fifth, the distribution of the fresh dry air over the evaporating surfaces; sixth, the promptness with which the moistened air is removed.

The accompanying table shows that the quantity of moisture 1 cu. ft. of air will take up increases greatly as the temperature rises. An increase of about 25° F. doubles its capacity for absorbing moisture. Hence, all other conditions remaining the same, the time required to accomplish the

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drying in a drying chamber will be reduced about one-half for every 25° F. increase of temperature. This proves the value of a high temperature in the dryer.

MOISTURE IN AIR.

Temperature. Degrees F.	Percentage of Saturation.						
	40	50	60	70	80	90	100
	Weight of Moisture, in Grains per Cubic Foot of Air.						
—10	.114	.142	.171	.200	.228	.256	.285
— 5	.148	.185	.222	.259	.296	.333	.370
0	.192	.240	.289	.337	.385	.433	.481
5	.244	.305	.366	.427	.488	.549	.610
10	.310	.388	.466	.543	.621	.698	.776
15	.394	.493	.592	.690	.789	.887	.986
20	.494	.618	.741	.864	.988	1.112	1.235
25	.620	.776	.931	1.086	1.241	1.396	1.551
30	.774	.968	1.161	1.354	1.548	1.742	1.935
35	.946	1.183	1.420	1.656	1.893	2.129	2.366
40	1.140	1.424	1.709	1.994	2.279	2.564	2.849
45	1.366	1.707	2.048	2.390	2.731	3.073	3.414
50	1.630	2.038	2.446	2.853	3.261	3.668	4.076
55	1.940	2.424	2.909	3.394	3.879	4.364	4.849
60	2.298	2.872	3.447	4.022	4.596	5.170	5.745
65	2.713	3.391	4.069	4.747	5.426	6.104	6.782
70	3.192	3.990	4.788	5.586	6.384	7.182	7.980
75	3.742	4.678	5.614	6.549	7.485	8.420	9.356
80	4.374	5.467	6.560	7.654	8.747	9.841	10.934
85	5.094	6.368	7.642	8.915	10.189	11.462	12.736
90	5.916	7.395	8.874	10.353	11.832	13.311	14.790
95	6.850	8.562	10.274	11.987	13.699	15.412	17.124
100	7.906	9.883	11.860	13.836	15.813	17.789	19.766
105	9.100	11.375	13.650	15.925	18.200	20.475	22.750
110	10.445	13.056	15.667	18.278	20.890	23.501	26.112
115	11.955	14.943	17.932	20.921	23.910	26.898	29.887
120	13.646	17.057	20.468	23.880	27.880	30.703	34.115

The volume of air required to pass through a laundry drying room depends on the size of the dryer, the temperature maintained therein, the number of changes of air per

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hour, the amount of moisture in the goods to be dried, and the temperature and humidity of the incoming air. The range of temperature in the United States may be taken from 0° F. to 100° F., and the range of relative humidity from 40 to 100 per cent. It will thus be seen that a much greater volume of air will be required in a dryer on a hot, humid day in summer than on a clear, cold day in winter.

Since one change per minute gives good results in ordinary practice, an easily remembered simple empirical rule is as follows:

Rule.—*Multiply together the length, depth, and height of the drying room, in feet; the result is the volume of air required per minute.*

Another method of determining the volume of air required is to calculate it on the basis of the amount of moisture to be evaporated. Each square foot of wet goods taken from the centrifugal extractor will contain, approximately, 2 oz. of water for thin goods, such as sheets, towels, pillow cases, etc., and from 2 to 3 oz. of moisture per sq. ft. for single thicknesses of blankets and other woolen fabrics. The temperature of the air in the dryer being maintained at, say, 120° F., 1 cu. ft. of air at that temperature is capable of absorbing 34.115 gr. of moisture.

The number of grains of moisture in an ounce is 437.5. Therefore, $437.5 \div 34.115 = 12.82$ cu. ft. of air is required to absorb 1 oz. of moisture. In order that the surcharged air shall be disposed of quickly and before it reaches the point of maximum saturation, it is good practice to provide for 1.5 times the theoretical amount of air to be delivered to a drying chamber, in order to dry all kinds of materials in the same length of time, and to provide for other contingencies, such as radiation of heat and leakage of air through the walls and crevices of the chamber, imperfect circulation of air, etc.

To compute the volume of air to be delivered to a dryer per minute, on the basis of evaporating the moisture contained in the wet fabrics, the following rule may be applied:

Rule.—*Multiply the number of square feet of wet material in*

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each rack by the number of racks in the dryer. Multiply this product by the number of ounces of moisture in each square foot of wet material and by the number of cubic feet of air required, at the temperature maintained in the dryer, to absorb 1 oz. of moisture; then multiply by 1.5 and divide the product by the time, in minutes, required to accomplish the drying. The result will be the number of cubic feet of air required in the drying room per minute.

A dryer with forced circulation is more efficient than one with natural circulation, accomplishing the drying in about one-third the time required by the natural-draft dryer, the difference in time depending on the height and size of the natural-draft vent stack and flues.

The vent flue and stack should have cross-sectional areas of .34 sq. in. for each cubic foot of the contents of the drying closet. When air is admitted through holes at the base of the closet, the total area of the holes should be equal to the area of the flue.

The areas of the flues and air openings, in square inches, may be found by the following rule:

Rule.—*Divide the number of cubic feet of air supplied to the drying closet per minute by the velocity of the air-current, in lineal feet per minute, and multiply by 144.*

Should it be desired to accomplish the drying in less time than 1 hr., a larger quantity of air and a corresponding increase in the sizes of the flues and air openings would be necessary. The velocity in the air flues may be 600 ft. per min. The velocity at the air openings of the dryer should be about 300 ft. per min.

It has been found, by experience, that approximately 1 lin. ft. of 1″ pipe per cu. ft. of space is usually required in the dryer. A more accurate method that is suited to any case arising in practice is given in the following rule:

Rule.—*Ascertain the amount of heat, in B. T. U., to be supplied to the dry room per hour; next, find the difference in temperature between the air to be heated and the steam in the heating coil. Find the coefficient of heat emission by referring to table headed "Heat Emission," and multiply this coefficient by the*

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difference in temperature, in degrees F., to obtain the total heat emission per square foot of radiating surface per hour. Then, the number of square feet of radiating surface required may be found by dividing the total amount of heat, in B. T. U., required per hour by the emission from 1 sq. ft. of radiating surface. The number of lineal feet of 1" pipe required in the coil may be found by multiplying the number of square feet of radiating surface by 2.9.

To find the number of B. T. U. required to evaporate the moisture in the wet goods in a dry room at a temperature of 120°, the following rule may be used:

Rule.—*Multiply the number of square feet of wet surface in the dry room by the number of ounces of moisture in 1 sq. ft. of the material to be dried, divide by 16 and multiply the quotient by 1,020, which is the number of B. T. U. required to evaporate 1 lb. of water at a temperature of 120°.*

The total emission of heat per square foot of radiating surface per hour for each degree difference in temperature is given in the following table:

HEAT EMISSION.

Velocity of Air. Feet per Second.	Heat Emitted. B. T. U.
3	3.42
4	4.00
5	4.50
6	4.94
7	5.33
8	5.71

The velocity of air when natural draft only is used rarely reaches 8 ft. per sec., and 3, 4, or 5 ft. are fair averages of velocities under conditions of natural circulation.

The efficiency of laundry drying apparatus depends not only on the thoroughness with which the wet materials are spread out and exposed to the air-currents, but also on the equal distribution of air in the drying chamber.

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NON-CONDUCTING PIPE COVERINGS.

The efficiencies of various non-conducting pipe coverings now on the market vary much less than is usually stated in advertising literature. It has been found, by experiment, that for each material there is a certain thickness that gives the best result, and that a further increase in thickness adds but little to the efficiency. Therefore, data based on a uniform 1 in. thickness of the non-conducting material are liable to be misleading.

The appended table gives, in round numbers, the approximate percentage of heat transmitted through various pipe coverings, taking the heat loss from an uncovered pipe as 100 per cent. Pipe coverings on the market, it should be noticed, vary considerably in wearing quality and efficiency.

PIPE COVERINGS.

Substance.	Heat Loss. Per Cent.	Substance.	Heat Loss. Per Cent.
Pipe without covering	100	Asbestos paper, 2 thicknesses	75
Pipe painted with black asphaltum	105	Asbestos, molded, mixed with plaster of Paris	30
Pipe painted with light drab lead paint	107	Asbestos and wool felt	20
Pipe painted glossy white	95	Magnesia, molded, applied in plaster form	25
Asbestos paper, two layers, 1-in. hair felt, canvas covered	15	Magnesia, as a class	20
Asbestos paper, 4 thicknesses	50	Mineral wool, as a class	20
		Rock wool, as a class	22
		Fossil meal, as a class	25

The various kinds of pipe coverings on the market are usually finished with a jacket of canvas sewed on; this is then given two coats of paint having the desired color. Either iron bands or, if an especially neat appearance is desired, polished brass bands are usually placed over the jacket every 2 or 3 ft. apart.

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HOT-WATER HEATING.

CIRCULATION.

The circulation in a hot-water heating system is a movement of hot water from the boiler to the radiators, where it parts with some heat, and a consequent movement of colder water from the radiators to the boiler to become reheated. Without circulation, heat cannot be conveyed from the boiler to the radiators. The velocity of circulation depends chiefly on: (*a*) the difference between the mean density of the ascending current and that of the returning current; (*b*) the vertical height of circuit above the boiler; and (*c*) the resistance to flow due to friction, change in direction, etc. The theoretical velocity could easily be computed, but as the actual velocity bears no definite ratio to the theoretical, the latter is of little value to the practical man.

With a given fall of temperature, the force of the circulation through radiators, etc., depends chiefly on the height of the return column, being, in many cases, practically independent of the height of the supply column. Thus, in the accompanying illustration, the force of circulation through the radiator *a* will be about 3 times as great as through *b*, notwithstanding the fact that the supply columns *c* and *g* are of equal height, because the return *f* is about 3 times as high as the return *e*. The temperature in the pipes *c* and *d* is supposed to be nearly the same; consequently, the column *d* simply balances an equal height of column *c*, and fails to supply any force for circulation. The force for circulation in this circuit, therefore, depends on the preponderance of the water in *e* over that contained in the riser below the level of the radiator at the line *h h*.

A *simple circuit* is one in which the water flows directly to a radiator through a single pipe without branches, returning directly to the boiler. Each circuit of the system is then entirely independent of the others.

In a *compound circuit*, the water circulates in comparatively large flow mains and return mains connected by small

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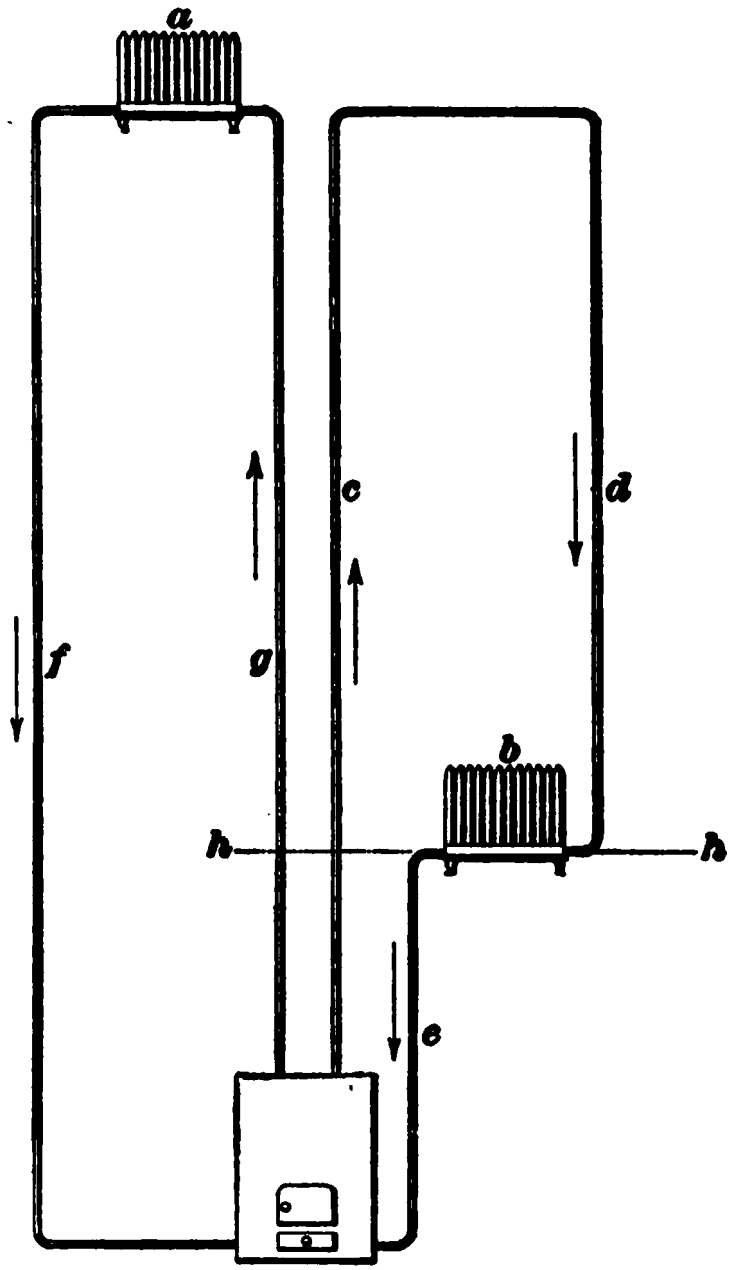
radiator branches that provide a number of direct circuits between the flow and return mains.

In some systems of hot-water circulation, the flow and return mains are connected only by the radiator branches,



and there is no way of maintaining a flow of water through them when the radiators are shut off. This arrangement of mains is called an *open circuit.* When the hot-water main

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connects with the return main independent of the radiator branches, the arrangement is called a *closed circuit.* As long as a good fire is maintained in the boiler, there will be an active circulation in the mains, and the water will be always at the maximum temperature, so that any or all of the radiators may be promptly supplied with hot water as soon as the valves are opened.

There is quite a difference of opinion regarding the true meaning of the terms "open" and "closed" circuits. The terms and the meanings thereof, as adopted by us, may seem contrary to local usage, but they coincide with the meanings of the same words as applied in the electrical professions, and therefore will help to prevent confusion or misunderstanding.

PIPING SYSTEMS.

One-Pipe, or Single-Main, System.—Fig. 1 shows what is commonly called the *one-pipe system*, but the name is a misnomer. While it is practicable to operate a steam-heating system with

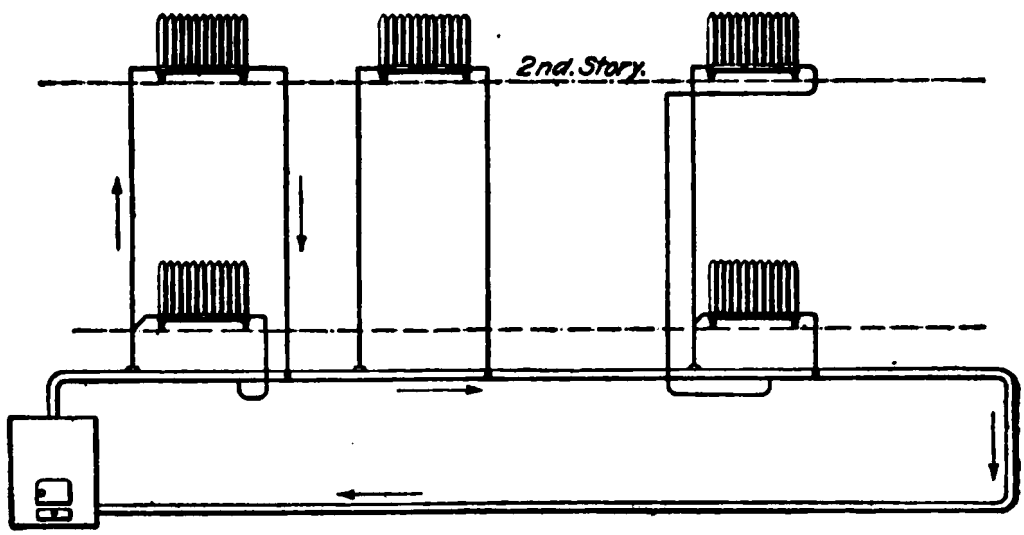

FIG. 1

a single main, and with single connections to the radiators, it is impracticable to do so with hot-water systems, because hot-water radiators must have two connections. The nec

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approach to a one-pipe system of hot-water distribution is obtained by connecting both the flow and return branches of the radiators to the same main, substantially as shown in Fig. 1. The main is of unusually large diameter, acting as a reservoir, so that the movement of the water through it is comparatively slow. The risers are tapped into the top of the main, and the returns are connected into the side or bottom, as shown in Fig. 2, so that they deliver the cooled water into the lower part of the main.

In the *high-pressure*, or *closed*, *system* the temperature of the water may be from 212° to 400°, or even more. When there is no objection to high temperatures and the accompanying risks, it may be used instead of the low-pressure system. It

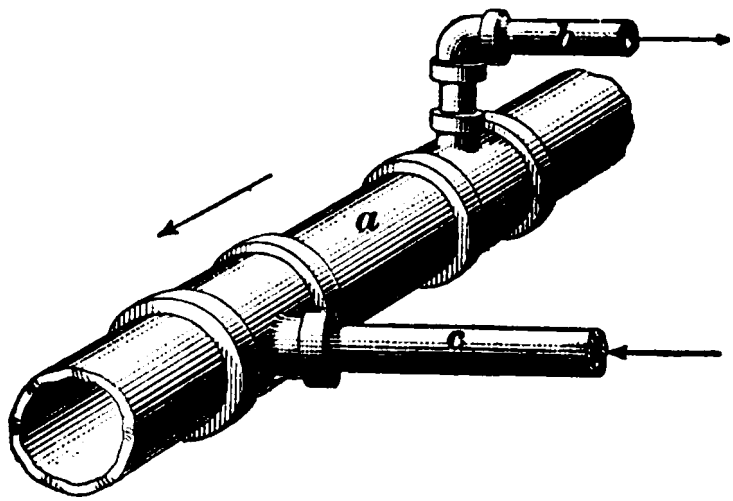

FIG. 2

requires strong boilers and radiators, the pressure at 250° being about 121 lb. per sq. in. by the gauge, but the apparatus is much smaller than that used for low-pressure heating. The range of temperature at the radiators is great, sometimes amounting to 150°, or more; consequently, the pipes may be made quite small. Usually, however, the range is about 50° or 60°, giving a motive force about 3 times as great as in low-pressure apparatus.

The *low-pressure*, or *open*, *system* operates with a maximum temperature of 210° or 212°, and the range of temperature is

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usually 20°. The area of heating surfaces must, therefore, be quite large. The motive force is so small that the size of the distributing pipes and mains of extensive heating systems becomes inconveniently large, the large pipes adding greatly to the cost of the apparatus.

In a one-pipe system of hot-water heating, the main is usually carried around the basement walls exactly as for steam heating, the return connection being made near the boiler.

Equalized System.—The distinguishing feature of the *equalized hot-water heating system* is that the water is compelled to travel exactly the same distance in going to and from any radiator on a given floor. Thus, a radiator situated close to the riser will have but little advantage over one on the same level situated a long distance away.

Resistance of Circuits.—The resistance in a bend made with a common elbow, the ends of the pipes being left square, is about equal to the frictional resistance of a piece of straight pipe having a length equal to 100 times its diameter. If the ends of the pipes are reamed, the resistance may be reduced to 70 or even to 60 diameters. With a long bend having a radius of 5 diameters, the resistance falls to about 10 diameters.

A plain T offers about the same resistance as an elbow, and a return bend from 1½ to 2 times as much. The gain made by reaming the ends of the pipe is much less in pipes of large diameter than in pipes of small diameter.

To the measured or actual length of any circuit should be added a length of pipe having a resistance equivalent to that of all the fittings. For example, in a circuit having an actual length of 300 ft., there are 8 elbows and 12 T's. Allowing 70 diameters for each elbow and T, the length to be added to the actual length of circuit to represent the resistance of the fittings, would be $(8 + 12) \times 70 = 1{,}400$ times the diameter of the pipe. In the case of a 4″ pipe this would equal 467 ft., making the computed length $300 + 467 = 767$ ft.

The actual length of a circuit is always understood to be the actual distance traveled by the water in going from and returning to the boiler.

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When the water flows through pipe coils, the actual distance traveled must be ascertained and included in the estimate of length of the circuit, and full allowance must be made for each return bend. It is found by experience that the ordinary flow and return connections from a radiator to the risers or mains having an aggregate length of about 10 ft., and including 6 ordinary elbows or their equivalents, will present about the same resistance to the flow of water as a plain, straight pipe 100 ft. long. Therefore, in computing the friction in a circuit, about 100 ft. should be added to the actual length for each ordinary radiator connection.

For general purposes it is assumed that the water will cool 20° in passing through the radiators, and will thus emit 20 B. T. U. per lb., or 166.7 B. T. U. per Winchester gal. (231 cu. in.).

PROPORTIONS OF HOT-WATER HEATING APPARATUS.

The sizes of pipes should be governed by the amount of radiating surface to be supplied, the height of the radiators above the boiler, and the number of changes in the direction of the several currents. It is considered safe practice to allow from 50 to 100 sq. ft. of direct radiation for each square inch of cross-section in the pipe. If the pipes are short, straight, and high, 1 to 100 would be allowed; if long, crooked, or low, 1 to 50 or more, according to the conditions.

In proportioning single-main, or one-pipe, systems satisfactory results will be obtained when the diameter of the flow and return mains is not less than .16 times the square root of the radiation supplied.

To determine the amount of radiating surface necessary to easily warm a building in all kinds of weather, and to proportion it so that each room will have the required temperature at the same time, are very important points, requiring careful consideration. No rules that will be applicable to all cases can be given, but for ordinary buildings having the average wall and glass exposures, the following table is found, in practice, to give good results, when used with judgment.

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RATIO OF HOT-WATER RADIATING SURFACE TO VOLUME OF ROOM.

DIRECT RADIATION. AVERAGE TEMPERATURE IN RADIATORS, 160° F.

Name of Room.	Ratio, 1 Square Foot to Cubic Feet.
Living rooms, one side exposed	32
Living rooms, two sides exposed	30
Living rooms, three sides exposed	28
Sleeping rooms	30– 40
Hall and bathrooms	20– 30
Schoolrooms and offices	30– 50
Factories and stores	50– 70
Auditoriums and churches	80–100

For direct-indirect radiation allow at least 25 per cent. extra. For indirect radiation allow 50 per cent. extra.

Due allowance must be made for leakages through loose doors, windows, etc.

TAPPINGS.

SIZES OF TAPPINGS FOR HOT-WATER RADIATORS.

Direct Radiators.				Indirect Radiators.	
First Floor.		Second Floor.			
Surface. Square Feet.	Size. Inches.	Surface. Square Feet.	Size. Inches.	Surface. Square Feet.	Size. Inches.
0– 18	¾	0– 24	¾	0– 24	1
18– 40	1	24– 54	1	24– 50	1¼
40– 70	1¼	54– 94	1¼	50– 80	1½
70–120	1½	94–160	1½	80–120	2

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RADIATING SURFACE SUPPLIED BY HOT-WATER MAINS.

DIRECT RADIATION. FALL OF TEMPERATURE, 20°. HEIGHT OF CIRCUIT, FROM 10 TO 15 FEET.

Nominal Diameter of Pipe. Inches.	Total Estimated Length of Circuit. Feet.										Factor for Indirect Heating.
	100	200	300	400	500	600	700	800	900	1,000	
1	50										.60
1¼	90	64									.60
1½	140	98	85	70							.60
2	250	176	153	125	113	103	95				.60
2½	360	256	220	180	162	148	137	126	119	112	.64
3	540	385	329	270	243	221	205	189	178	167	.70
3½	750	533	458	375	338	308	285	263	248	233	.70
4	1,000	710	610	500	450	410	380	350	330	310	.80
4½	1,400	980	854	700	650	574	532	490	462	434	.80
5	1,800	1,278	1,098	900	810	738	684	630	594	568	.80
6	2,700	1,917	1,647	1,350	1,215	1,107	1,026	945	891	837	.80
7	4,000	2,840	2,440	2,000	1,800	1,640	1,520	1,400	1,320	1,240	.80
8	5,400	3,850	3,290	2,700	2,430	2,210	2,050	1,890	1,780	1,670	.82
9	7,200	5,112	4,392	3,600	3,240	2,952	2,736	2,520	2,376	2,232	.84
10	9,600	6,800	5,800	4,800	4,300	3,900	3,600	3,400	3,200	3,000	.86

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DIAMETER OF RADIATOR CONNECTIONS.

DIRECT RADIATION. FALL OF TEMPERATURE, 20°.

Size of pipe, in inches	¾	1	1¼	1½	2	2½
Area, in square feet	18	40	70	120	200	300

For indirect hot-water heating, the sectional area of the mains should approximate the sum of the area of the branches taken therefrom, but where there is no indirect work, the sizes may be less.

All fittings used on hot-water mains should have easy curves and the branches should be Y's, to reduce resistance to a minimum. Special distributing fittings should be used to induce circulation through radiators on the first floor.

SIZES OF MAINS AND BRANCHES.

Sizes of Main. *Sizes of Branches.*

1″ will supply two ¾″.
1¼″ will supply two 1″; or one 1″ and two ¾″.
1½″ will supply two 1¼″; or one 1¼″ and two 1″.
2″ will supply two 1½″; or one 1½″ and two 1¼″.
2½″ will supply two 1½″ and one 1¼″; or one 2″ and one 1¼″.
3″ will supply one 2½″ and one 2″; or two 2″ and one 1½″.
3½″ will supply two 2½″; or one 3″ and one 2″; or three 2″.
4″ will supply one 3½″ and one 2½″; or two 3″; or four 2″.
4½″ will supply one 3½″ and one 3″; or one 4″ and one 2½″.
5″ will supply one 4″ and one 3″; or one 4½″ and one 2½″.
6″ will supply two 4″ and one 3″; or four 3″; or ten 2″.
7″ will supply one 6″ and one 4″; or three 4″ and one 2″.
8″ will supply two 6″ and one 5″; or five 4″ and two 2″.

All flow and return pipes should be of the same size.

All pipes must rise from the boiler to the radiators with a pitch of at least 1 in. in 10 ft.

The expansion-tank capacity should be at least one-twentieth that of the entire apparatus, if it is an open tank. Closed tanks are not recommended.

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RADIATING SURFACE SUPPLIED BY HOT-WATER RISERS.

DIRECT RADIATION. FALL OF TEMPERATURE, 20°.

Diameter of Riser. Inches.	Floor on Which Radiator Is Located.					
	1	2	3	4	5	6
¾	18	25				
1	36	50	62	71		
1¼	65	92	112	128	145	
1½	100	141	172	198	224	244
2	180	253	309	356	403	439
2½	260	266	447	515	582	634
3	370	521	636	732	828	902
3½	540	761	928	1,069	1,210	1,318
4	720	1,015	1,238	1,425	1,612	1,756

The manner of determining the proper sizes of the various parts of a hot-water piping system, by means of the foregoing tables, may be explained by means of the accompanying illustration, which shows the area of heating surface of each radiator, the height of the various risers, and the length of the horizontal branches and mains. The figures having the symbol □ attached to them, thus: 60 □, indicate the area, in square feet, of the radiator at that branch. The risers are numbered *No. 1*, *No. 2*, etc. for convenience in reference.

Having a suitable working drawing, the work of computing the diameters of pipes should begin at the point most remote from the boiler, which, in this case, is the radiator on the fourth floor on riser *No. 4*.

The riser must supply water sufficient for 60 sq. ft. of heating surface at that point. Referring to the last table given, it appears that a 1¼″ pipe will serve a maximum of 128 sq. ft. on the fourth floor; in order to reduce as much as possible the frictional resistance to the flow of water a 1¼″ pipe therefore should be used.

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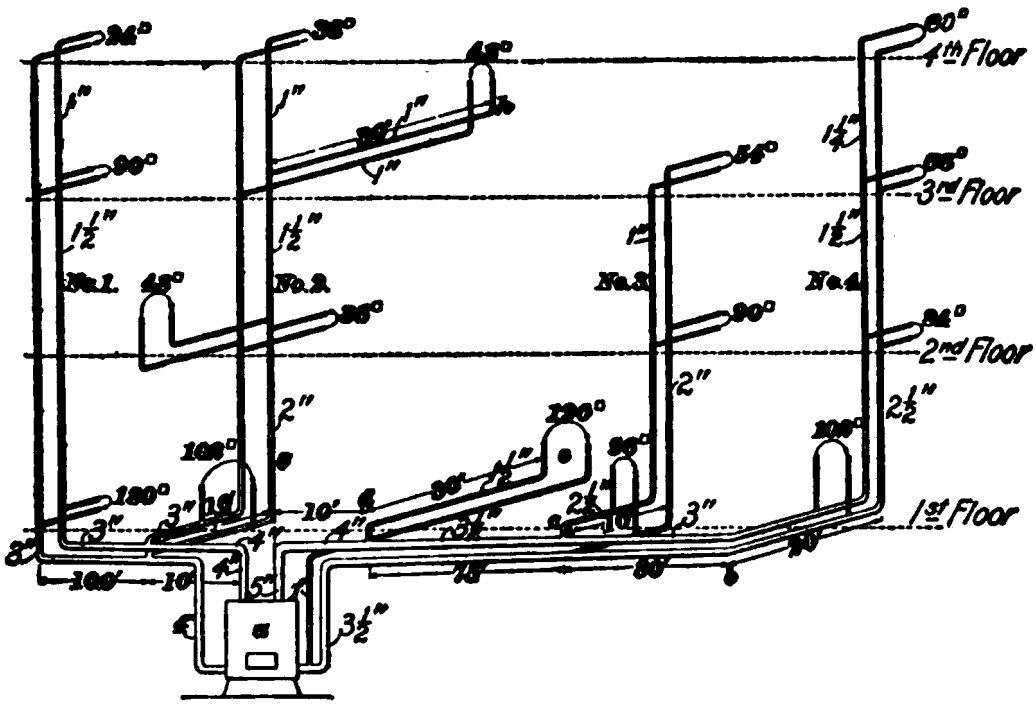
The pipe leading from the second to the third floor must supply the 60′ radiator on the fourth floor and also the 66′ radiator on the third floor—a total of 126 sq. ft. The table shows that a 1¼″ pipe should be used to supply 126 ft. of radiation on the third floor, the next smaller size being a trifle too small.

The riser from the main to the second floor must supply three radiators, aggregating 210 sq. ft. The table shows that 2″ pipe is a little larger than is necessary; but it should be noted that there are elbows at the foot of these pipes; therefore, it is wise to use pipe of 2½″ diameter.



The sizes of the other risers should be determined in a similar manner. The horizontal lines may then be considered. That portion of the main extending from *No. 4* riser to the connections to *No. 3* must supply a first-story radiator in addition to *No. 4* riser, aggregating 312 sq. ft. The length of the flow pipe is 100 ft., which, added to the same length of return pipe, makes a circuit of 200 ft. Referring to the table of sizes of mains, it appears that 312 sq. ft. of

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surface, on a 200′ circuit, requires a 3″ pipe. This size is a little larger than that actually required, and will compensate for the elbows at *b*.

At the point *c* another circuit is attached, *No. 3*, which supplies 240 sq. ft. of heating surface, making the total surface to be supplied at that point 240 + 312 = 552 sq. ft. The distance between the points *c* and *d* is 75 ft., making the circuit 150 ft. long. The table, "Sizes of Mains," shows that 552 sq. ft. of surface, on a 200′ circuit, will require a 3½″ pipe. The return may be continued to the boiler with that size, but the flow main should be enlarged to 4 in. at *d* to provide for the radiator at *e*. Although the length of the connections to this radiator is much greater than is ordinarily found in practice, the radiator is comparatively close to the boiler, the branch connection is taken from the top of the main, and hence a 1½″ pipe is sufficiently large to supply it.

It will be noted that this radiator is also provided with an independent return connection, as shown at *f*. This construction insures a more positive and rapid circulation than if the return were connected into the return main at *d*. If the radiator were located close to the mains, there would be no considerable advantage in providing it with an independent return.

The circulation in circuit *No. 2* would probably be improved by providing the return pipe *g* with an independent connection to the boiler, instead of connecting it to the return main, as shown in the illustration.

The radiator *h*, on circuit *No. 2*, has long connections. As indicated further on, a given size of pipe will supply 1.72 times as much radiating surface on the third floor as on the first; hence, this radiator corresponds to one on the first floor having 48 ÷ 1.72 = 28 sq. ft. of surface. The preceding table shows that 1″ pipes will be sufficiently large to furnish an adequate supply of hot water to the radiator.

The horizontal pipes on the upper floors of a building, and also the risers leading thereto, may be made smaller in diameter than those on the lower floors, because the force that impels the water increases with the height of the cir-

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cuits. The proper size of a pipe having been determined for a given service on the first floor, the diameter for equal service on higher floors—the temperatures remaining the same—may be found by multiplying by the following factors:

Story	2d	3d	4th	5th
Factor	.87	.80	.76	.73

The area of heating surface that may be supplied by a pipe of given diameter will increase as the circuit is made higher. If the area known to be right for a given size of pipe on the first floor is taken as 1, the areas on the upper floors will increase in the following order:

Story	2d	3d	4th	5th	6th
Proper area heating surface	1.41	1.72	1.98	2.24	2.44

BLOWER SYSTEMS OF HEATING.

PURPOSE, ADVANTAGES, AND REQUIREMENTS.

Blower systems are used for ventilating as well as warming buildings by forcing or by inducing a flow of air through them by means of fans. The terms *forced blast* and *hot blast* are frequently applied to such systems to distinguish them from natural, or gravity, methods of heating and ventilating buildings. Properly speaking, the term forced blast should be applied only to blower systems of the plenum or pressure type, in order to distinguish these from induced blast or exhaust systems. Strictly speaking, blower systems are those in which the air for warming and ventilation is supplied by cased fans or blowers.

Among the principal advantages in the use of the blower, or mechanical, systems of heating and ventilating are the following: Positive circulation of fresh air at a desired temperature, any and all parts of the building being warmed with like certainty; perfect ventilation, regardless of temperature; and positive movement of the heated air through the ducts and flues at a pressure independent of atmospheric conditions.

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The first requirement of installation is that the blower, at a predetermined speed, as fixed by the specifications under which the apparatus is installed, shall be sufficiently large to deliver the given quantity of air through the registers. Second, the heater outside or beyond the blower should have an excess of clearance area over the area of the fan inlet. Third, under ordinary conditions the heater should not be less than 20 coils in depth to maintain a temperature of 70° inside the building with zero weather outside. Fourth, the area of discharge from the bases of the coils should be approximately that of the steam-supply connections when working at very low or atmospheric pressure. Fifth, main and branch ducts should be so proportioned as to produce a uniform flow of air and reduce frictional resistance to a minimum. Sixth, metal ducts should be covered with some form of non-conducting material, especially where the delivery ducts are long.

In designing a blower system of heating and ventilation, it is considered good practice to provide for a maximum supply of air under the most unfavorable conditions likely to arise. In hot-blast heating, more failures result from lack of space around and between the pipes of the heater than from any other cause; lack of sufficient area there greatly reduces the amount of air that the fan is capable of delivering.

CLASSIFICATION OF BLOWER SYSTEMS.

The Plenum System.—The plenum system takes its name from the fact that the pressure of the air within the building is greater than that of the outer atmosphere. The blower forces air into the rooms in greater volume than it is removed by the ventilating flues, the balance leaking out around windows and doors. This tends to check the in-leakage of cold air.

The heating apparatus employed in conjunction with a fan may be of any desirable type, that is, either steam, hot water, or hot air.

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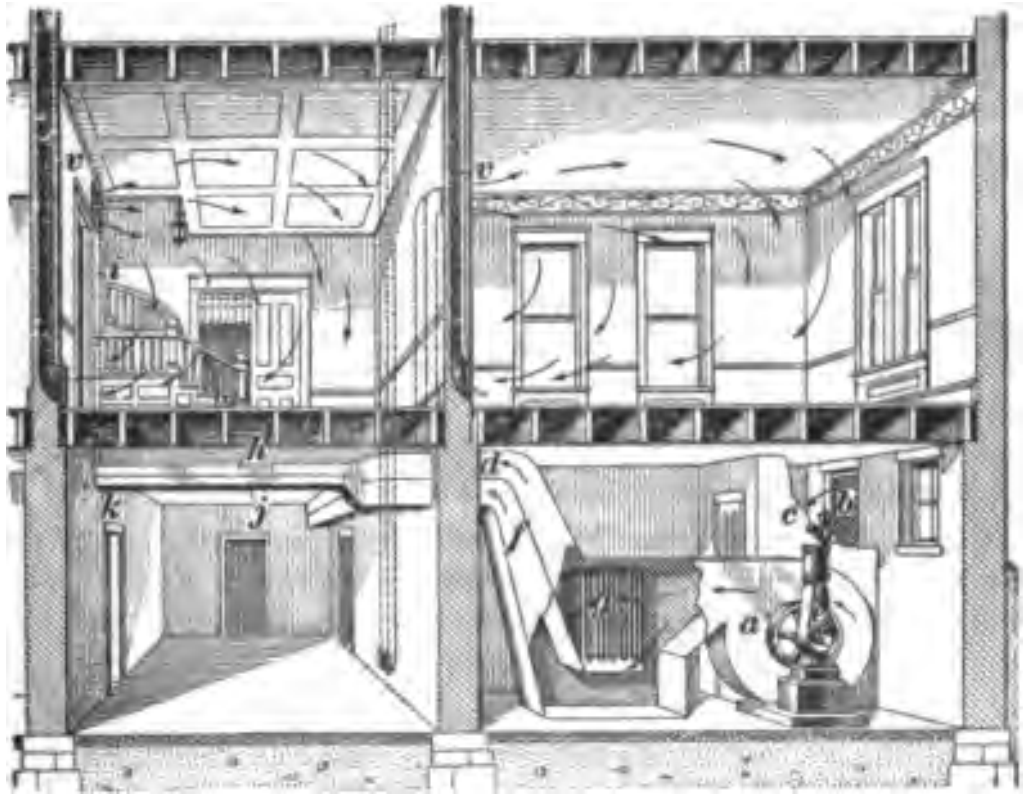
Buildings are commonly ventilated on the plenum system in the manner indicated in the accompanying illustration. A fan *a*, placed in what is usually called the fan room, in the basement of the building, takes its supply of fresh air from the outer atmosphere through a wire-screen window *b* in the fresh-air inlet room *c*. The fan wheel is revolved by a small vertical engine *e*, connected to the shaft of the fan wheel. The fan wheel, when in motion, forces fresh air into the main ducts, either through and between the surface of a steam-



heated coil *g* and into *d*, or under the coil and into *f*. The air in *d*, then, is warm, and that in *f* is cold. Hot and cold branches *h* and *j* are taken from the main ducts and join the base of a vertical flue *i*, built in the wall; a mixing damper is placed at the point *k* to allow mixing the hot and cold air, to obtain the proper temperature without affecting the volume of air discharged. Each room to be ventilated is furnished with an outlet or vent flue *v*, which passes out through the roof to the atmosphere.

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The Exhaust or Vacuum System.—The vacuum system takes its name from the fact that the air pressure within the building is slightly less than that of the outer atmosphere, because the fan removes air from the rooms and blows it to the outer atmosphere. Air may be moved and distributed by the exhaust or vacuum system with the same facility as by the plenum system; but the inward leakage of cold air that takes place through every hole and crevice in the walls, and around every loose-fitting window, produces cold drafts in the rooms.

Combined Plenum and Exhaust Systems.—Under all ordinary circumstances, the combination of an exhaust system with a pressure or plenum system is not to be recommended. The combination does not afford any decided advantage, and there are several substantial objections to it. The cost for flues, fans, power, motors, installation, and attendance is greater than in a single pressure system of equal aggregate capacity. For very large plants, however, a combination of the pressure and exhaust system is sometimes considered advisable.

GENERAL ARRANGEMENT OF APPARATUS.

Methods of Installation.—With reference to the element of heating alone there are three methods of installing blower systems: first, so that a constant volume of air is warmed by heating surfaces massed in a heater close to the fan, the air being distributed by a single- or double-duct system; second, so that the air is warmed or reheated, as the case may be, by separate radiating surfaces, arranged, as for indirect heating, at the base of the flues, a single duct serving to convey the fresh air from the fan to the heating surface; third, so that tempered air at from 70° to 75° is forced through a single-duct system into the rooms, where sufficient direct radiation is placed to give the required temperature and to provide against entire absence of heat in case of accident to the fan or main heater. Considered with reference to the method of distributing the warmed air, blower systems may be divided into two classes, viz., single-duct systems and

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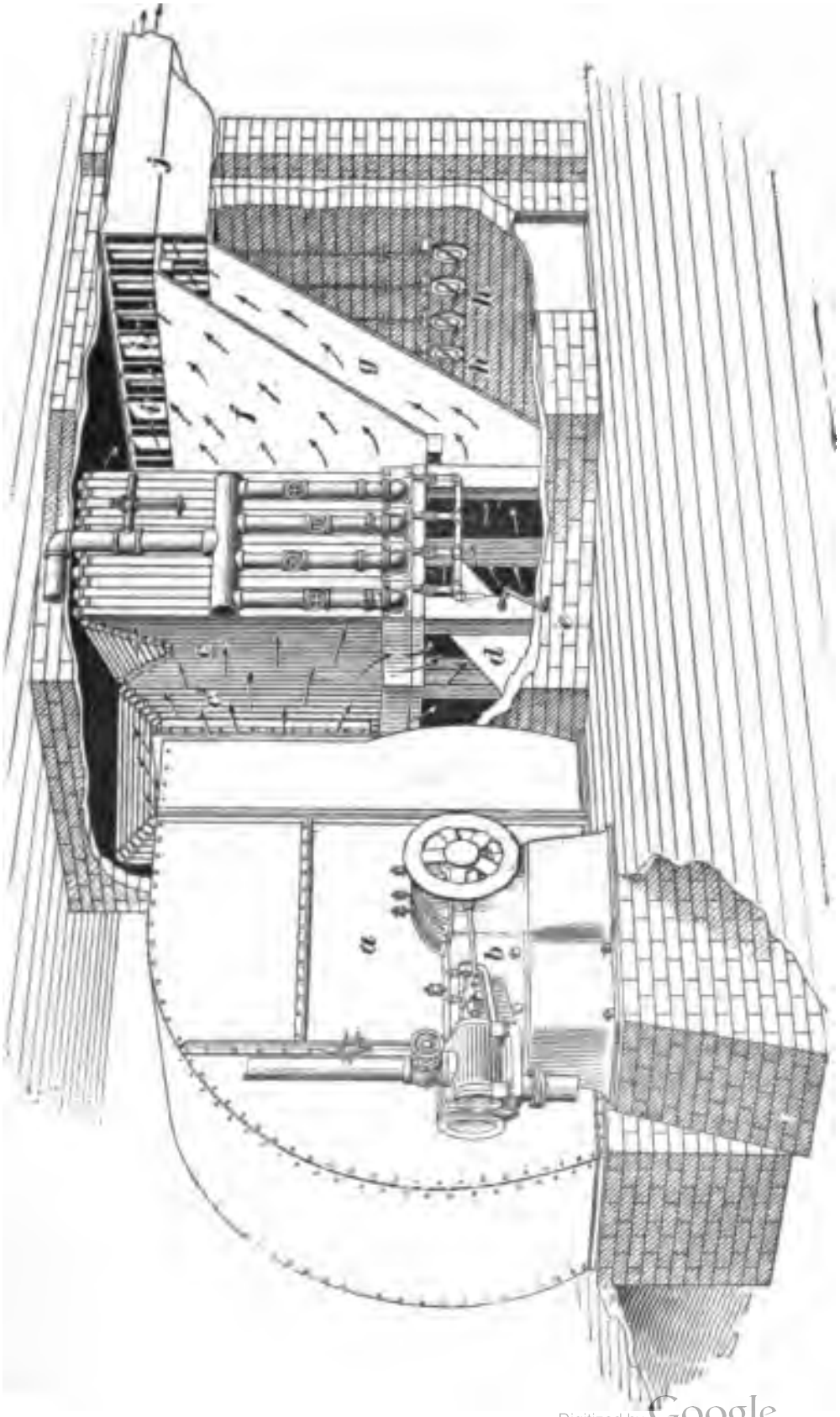

FIG. 1.

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double-duct systems. With the former, the mixture of hot and cold currents of air takes place close to the fan, whereas with the latter, the hot and cold air are carried in separate ducts to the base of the flues in which the mixing is done.

Single-Duct System.—One of the methods of arranging the apparatus for use in connection with a single-duct system of distribution is illustrated in perspective in Fig. 1. The three-quarter housing steel-plate fan *a*, driven by the hori-

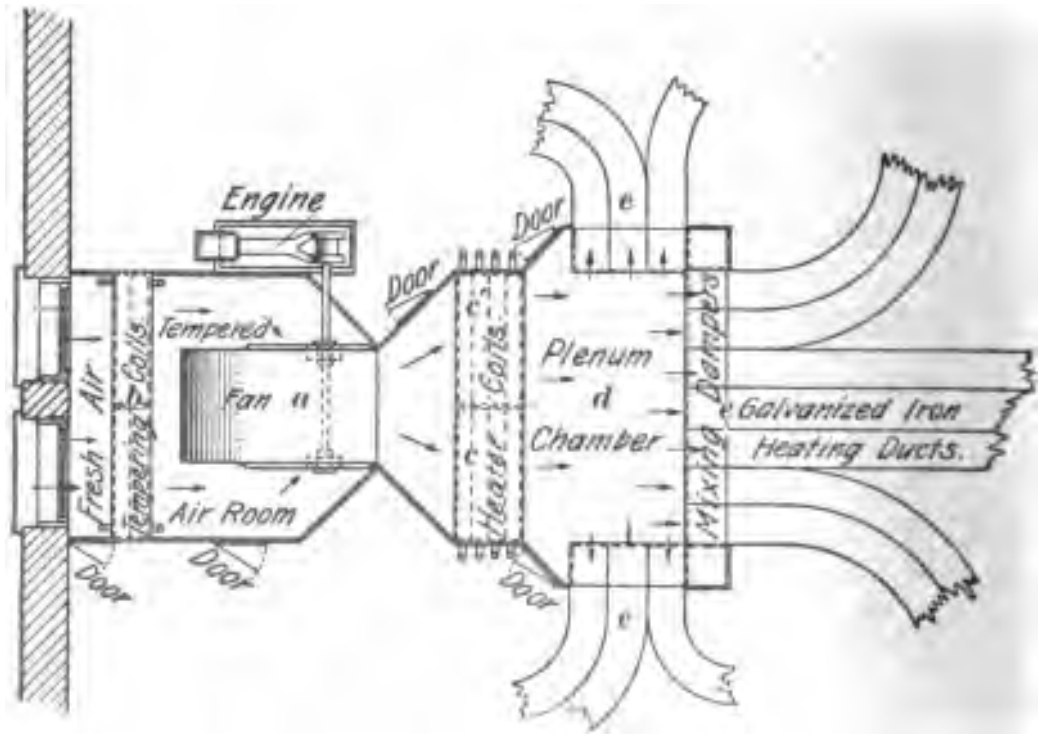

FIG. 2.

zontal steam engine *b*, delivers air through its left-hand, top, horizontal discharge outlet into the brick receiving chamber in which, on a raised platform, is mounted a duplex heater *c c'*, over and between the pipes of which the air is forced by the fan to the ducts beyond. Beneath the heater is arranged a by-pass controlled by the damper *d*, operated by the hand crank *e* outside the plenum chamber. The partition *f* serves to separate the heated air from the cold air by-passed under the heater, while the partition *g* serves to form one side of the chamber in which the motors *h*, *h* that operate the mixing

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dampers *i*, *i* are mounted on the wall, as shown. The hot and cold air are mixed in an enlargement *j* of the ducts, the temperature of the air supplied to the various rooms being controlled by thermostats, in accordance with the operation of which the mixing dampers are actuated by their motors. The mixed air is distributed by single galvanized-iron ducts arranged, for instance, as shown in Fig. 2, where the fan *a* is placed within a sheet-metal, fresh-air room or chamber, drawing its supply of fresh air over a duplex tempering coil *b* and thence forcing it over a duplex main heater *c*, *c'* into the plenum chamber *d*, from which separate single ducts *e*, *e* lead to the various rooms. By means of doors in the metal casings, access is had to the main heaters, which are arranged side by side in the same plane.

Double-Duct System.—A common arrangement of apparatus for the double-duct system of distribution is composed of a blower driven by an upright engine, and forcing the air through a top horizontal discharge outlet between the pipes of the heater and thence to the main galvanized-iron air ducts. A portion of the cold fresh air is usually by-passed over the top of the heater into the cold-air duct. The quantity of air delivered to the cold-air duct depends on the position of the baffle-plate damper. Both ducts are carried to the base of the vertical flues, where the mixing takes place.

Relative Position of Fan and Heater.—The relative position of fan and heater determines whether the apparatus is of what is known as the *blow-through* or *draw-through* type, the adoption of either arrangement being dependent on the space available for the installation of the apparatus, on the size of the latter, and on the personal preference of the designer.

AIR SUPPLY FOR BUILDINGS.

Amount of Air Required.—The amount of air commonly supplied to each occupant, in various types of buildings, is given in the accompanying table. Some states, notably Massachusetts, have passed laws relating to the ventilation of school buildings and providing for a minimum per capita supply per minute in such buildings.

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AIR SUPPLY FOR DIFFERENT CLASSES OF BUILDINGS.

Class of Building.	Cubic Feet per Hour per Occupant.	Cubic Feet per Minute per Occupant.
Hospitals	4,000–6,000	66–100
Court rooms	2,000	33
Legislative halls	2,000	33
Theaters	1,500–1,800	25– 30
Halls	1,000–1,200	17– 20
Churches	1,000–1,200	17– 20
Schools	1,800–2,400	30– 40

The Massachusetts law demanding, in schools, an air supply of 30 cu. ft. per occupant per min. may readily be met. This volume has become the commonly accepted allowance for such buildings in communities where the importance of ventilation is properly appreciated. The per capita space in churches is generally 300 cu. ft. or more. Schools have about 200 cu. ft., and ordinary halls frequently have only 100 cu. ft., or even less.

To secure the air supply stated in the preceding table in halls having 100 cu. ft. of space per occupant, an air change once in about 5 min. would be necessary, whereas the same allowance per capita in churches would give a 15-min. air change.

Temperature of Air Supply.—In factories and buildings where heating and not ventilation is the main item, the air is commonly changed every 15 to 20 min., the inlet temperature being roughly 130° to 140°. In ordinary schools, with a frequent air change, say every 6 or 8 min., the room may be kept at 70°, with a temperature at inlet of less than 100°, even in severe weather. The heat given off by the occupants of a room has a decided effect on the temperature, so much, in fact, that in theaters with little or no exposure the air must frequently be admitted 5° or 10° lower than the temperature at which it is desired to keep the room.

In determining the proper temperature of the air supply,

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consideration must be given to the fact that an adult gives off per hour about 400 B. T. U.; a gas burner about 4,000 B. T. U.; an incandescent electric light about 1,600 B. T. U. The animal heat production of 80 persons is therefore, approximately, equivalent to 1 boiler H. P.

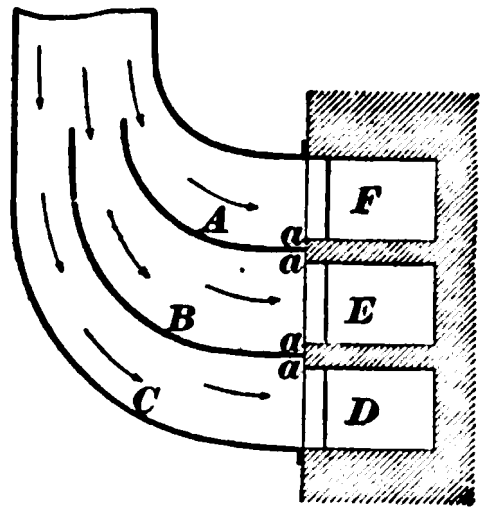

FIG. 1.

Splitting Air-Currents.—The proper manner of dividing a main current into three portions so as to supply branches or independent air flues is shown in Fig. 1. If the partitions *A* and *B* were absent, the greater part of the current would continue its motion until it was deflected by the side *C*. In that case, the flue *D* would receive a larger proportion of the current than either of the others, and the supply to the flue *F* would be quite insufficient.

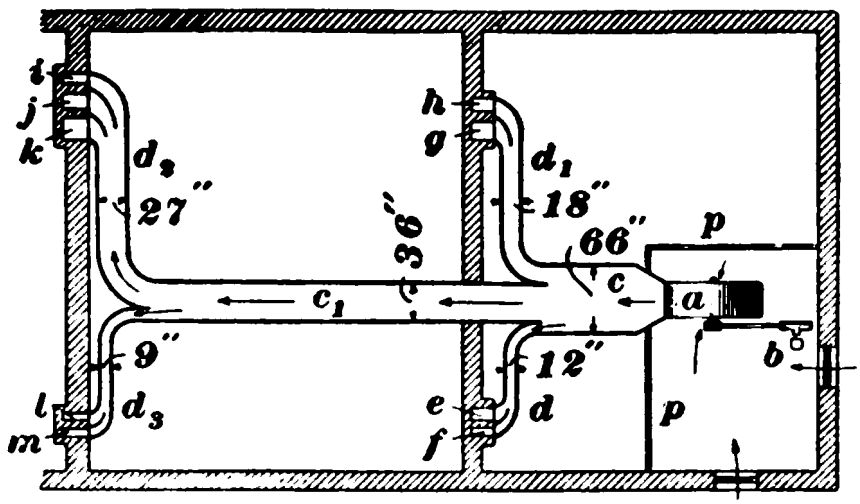

FIG. 2.

The shoulders *a*, *a* against which the air impinges ought to be beveled off, instead of being left square, as in the figure. A proper supply of air to each flue may be insured by adjusting the partitions *A* and *B* in such a manner that they will

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intercept the desired proportions of the main current before any change is made in its direction.

Fig. 2 shows the proper method of splitting up a main air-current into several smaller ones, and of subdividing these so as to supply a large number of vertical ducts. This illustration shows a centrifugal fan *a* set in a fan room that is formed by air-tight partitions *p*, *p*. The fan wheel is driven by a belt from the engine *b*. The air supply to the fan is taken in through the windows, as shown.

The fan forces the air into the main duct *c*, where it is split into three currents c_1, *d*, and d_1. The current *d* supplies two vertical flues *e* and *f*; d_1 supplies *g* and *h*. The current c_1 is then split into two unequal currents d_2 and d_3; the latter supplies the flues *l* and *m*, while the former supplies the flues *i*, *j*, and *k*.

FAN CAPACITIES.

Capacity of Disk Fans.—The fan capacities given in manufacturers catalogues may be attainable where fans are delivering freely, with no resistance due to the passage of air through ducts, registers, or heaters, or caused by wind pressure. Such ratings, if attainable with free delivery, must generally be reduced at least 50 per cent. when the fans are connected with heaters and ducts; under this condition the catalogue horsepower must be about doubled.

The results of tests made on three well-known propeller type fans, each arranged to discharge through a pipe 90 in. long and of the same diameter as the fan, showed that $V = .95\ D^3\ R$, where V = volume in cu. ft. per min., D = fan diameter in ft., R = revolutions per min. This formula is based on free delivery, but when a disk fan is used to force air through a system of ducts, or through a heater, the formula used in computing the table "Approximate Air Delivery of Disk Fans" should be used. This formula is

$$V = .6\ D^3\ R$$

The letters have the same meaning as in the previous formula. The horsepower given in the table is sufficient under the working conditions there stated.

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APPROXIMATE AIR DELIVERY OF DISK FANS.

Diameter of Fan. Feet.	Revolutions per Minute Against Ordinary Resistance of Ducts, Etc.	Delivery in Cubic Feet per Minute With 1,000 Feet Velocity in Duct Equal to Area of Fan.	Horsepower of Motor to Drive Fan Under Conditions Stated in Columns 2 and 3.
1½	870	1,770	¼
2	654	3,140	½
2½	523	4,910	¾
3	436	7,070	1–1½
3½	374	9,620	2–3
4	328	12,570	3–4
4½	292	15,900	4–5
5	262	19,640	5–6
6	218	28,300	6–7½

A velocity of 1,000 ft. per min. in a duct of the size of the fan should be considered a maximum in heating and ventilating work when using disk or propeller fans. The delivery for speeds not given in the table will be proportional to the revolutions per minute.

Capacity of Cone Fans.—The capacities of cone fans that are given in the appended table are safe ones to figure on under ordinary working conditions with fans drawing air through heaters and forcing it through ducts and flues. Under favorable conditions, fans of this type will deliver at least 10 per cent. more air than is stated in the table. The maximum number of revolutions at which it is customary to run such fans in connection with heating and ventilating systems is such as to secure a peripheral speed of about 4,500 ft. per min. A tip speed of 3,700 ft. per min. is a fair average. Many engineers favor the Briggs type of cone fan encased in a steel plate housing, using two fans set back to back, with a plate of iron between, taking in air on both sides of the casing. The principal objection to this style of fan is its expensive construction.

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CAPACITY OF CONE FANS.

(*Robert Briggs.*)

Diameter of Fan. Feet.	Revolutions per Minute.	Delivery. Cubic Feet per Minute.	Pressure. Inches of Water.
4	250–500	6,400– 12,800	.31 to 1.23
5	200–400	10,000– 20,000	.31 to 1.23
6	167–333	14,400– 28,800	.31 to 1.23
7	140–280	20,000– 40,000	.31 to 1.23
8	125–250	25,500– 51,000	.31 to 1.23
10	100–200	40,000– 80,000	.31 to 1.23
12	83–167	57,500–115,000	.31 to 1.23

Power Required to Drive Cone Fans.—The following table shows the approximate horsepower of motors required to drive cone fans at stated speeds. The efficiency of the fan is taken as 40 per cent.; efficiency of motor, 80 per cent.

POWER REQUIRED TO DRIVE CONE FANS.

Diameter of Fan. Feet.	Revolutions per Minute.	Approximate Motor Horsepower.	Standard Size Motor to Use.
4	291	3.20	3
5	232	5.00	5
6	194	7.20	7½
7	166	9.75	10
8	146	12.70	10
9	129	16.10	15
10	116	19.90	20
12	97	28.60	25

The horsepower required at other speeds than those stated will be proportional to the cube of the speeds. The horsepower in the blast, which is the basis of this table, was computed for an area just within the capacity of the fan, that is, the maximum area of opening through which the fan will discharge air at a velocity corresponding to the speed of the tips of the blades.

Properly designed motors of the medium and larger sizes

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should give over 80 per cent. efficiency. The approximate horsepower will therefore be less than stated in column 3. For example, a motor with 85 per cent. efficiency need be only $\frac{80}{85}$, or about 94 per cent. of approximate horsepower stated.

Capacity of Centrifugal Fans.—The capacity of centrifugal fans under usual working conditions, expressed in cubic feet of air delivered, may be obtained approximately by multiplying the cube of the diameter of the fan wheel, in feet, by the number of revolutions, and by a coefficient having a value, depending on the back pressure, of from .4, with a 1-oz. back pressure, to .6 for single-inlet fans under free discharge, a coefficient of .5 being used with a back pressure of 1 in. of water column.

The approximate capacities of blowers under ordinary working conditions in connection with heaters and distributing ducts, and the approximate indicated horsepower of engines, or nominal horsepower of motors, to drive them are given in the following table:

CAPACITY OF CENTRIFUGAL FANS.

Diam. of Wheel. Feet.	Width of Housing. Inches.	Revolutions per Minute.	Capacity. Cubic Feet per Minute.	Horsepower.	Revolutions per Minute.	Capacity. Cubic Feet per Minute.	Horsepower.	Revolutions per Minute.	Capacity. Cubic Feet per Minute.	Horsepower.
3	18	390	4,800	1.9	435	5,300	2.6	475	5,800	3.4
3½	21	330	6,200	2.4	370	7,000	3.4	400	7,600	4.4
4	24	290	8,000	3.0	325	9,000	4.3	360	9,800	5.7
4½	28	260	11,000	4.2	290	12,000	5.2	320	13,500	7.7
5	32	230	13,000	5.0	260	14,500	7.0	285	16,000	9.3
5½	36	210	17,000	6.6	240	19,000	9.3	260	21,000	12.2
6	42	195	23,000	8.8	220	25,000	12.4	240	28,000	16.1
7	48	170	30,000	11.8	185	34,000	16.4	200	36,000	20.0
8	48	150	33,000	13.0	165	37,000	18.1	180	41,000	23.8
9	54	130	42,000	16.6	145	47,000	23.2	160	52,000	30.6
10	60	115	54,000	20.9	130	60,000	29.2	140	66,000	38.4

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The speeds given in the table, "Capacity of Centrifugal Fans," cover the range ordinarily used in heating and ventilating work. The velocities through properly proportioned fan outlets are approximately 1,830, 2,030, and 2,260 ft. per min. for the several columns in the order stated.

The horsepowers are based on efficiencies of 40 per cent. for the fans and 80 per cent. for the motors. With motors of higher efficiency, the horsepower will be lower than stated in the table; that is, a motor of 88 per cent. efficiency need be only $\frac{80}{88}$, or about 90 per cent. of the horsepower given. An inspection of the table will show the economy of power gained by running fans at relatively low speeds; for example, to deliver 28,000 cu. ft. of air per min. a 6′ fan at 240 rev. may be used, requiring 16.1 H.P. Column four shows that 30,000 cu. ft. may be delivered by a 7′ fan at 170 rev. with a consumption of only 11.8 H. P. The difference in cost between the two sizes would not be great and would soon be made up by the saving in power. As a rule, it is not wise to run fans slower than the speeds stated in the third column.

The free-delivery capacity of cased centrifugal fans having wheels whose width at the blade tip is one-half their diameter, may be found, approximately, by multiplying the coefficient .000303 by the product obtained by multiplying the cube of the fan-wheel diameter, in inches, by the number of revolutions per minute. Expressed as a formula, in which

C = capacity, in cubic feet per minute;
D = diameter of fan wheel, in inches;
R = revolutions per minute,

we have $C = .000303\ D^3\ R$, from which it is evident that

$$D = \sqrt[3]{\frac{C}{.000303\ R}}$$

$$R = \frac{C}{.000303\ D^3}.$$

In order to render capacity calculations for fan wheels of different widths of blades and diameters easy, a table of factors made up from a table published by Mr. M. C. Huyett, is presented here. To obtain the capacity of centrifugal cased fans by the aid of this table, multiply the tabulated factor

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corresponding to the diameter and width of fan wheel, in inches, by the number of revolutions of the fan per minute. The product will be the free-delivery capacity of the fan, in cubic feet per minute. Thus, a fan 100 in. dia. and 38 in. wide, at 150 rev. per min. will deliver $230 \times 150 = 34{,}500$ cu. ft. of air per min.

FREE DELIVERY CAPACITY FACTORS FOR CENTRIFUGAL FANS.

Diam. of Wheel. Inches.	Width of Fan Wheel at Periphery. Inches.										
	18	20	22	24	26	28	30	32	34	36	38
36	14.1	15.7									
38	15.7	17.5									
40	17.5	19.4	21.4								
42	19.3	21.4	23.6	25.7							
44	21.1	23.4	25.8	28.2	30.5						
46	23.0	25.6	28.2	30.7	33.3	35.8					
48	25.2	28.0	30.8	33.5	36.3	39.1	41.9				
50	27.3	30.0	33.3	36.4	39.4	42.4	45.5	48.5			
52	29.5	32.8	36.1	39.3	42.6	45.9	49.2	52.5	55.8		
54	31.8	35.3	38.8	42.3	45.8	49.4	53.0	56.5	60.0		
56		38.0	41.7	45.6	49.4	53.2	57.0	60.7	64.5	68.3	
58		40.8	44.9	48.9	53.0	57.1	61.2	65.2	69.3	73.4	
60		43.6	48.0	52.3	56.6	61.0	65.4	69.8	74.1	78.5	82.8
62			51.3	55.9	60.6	65.2	69.9	74.5	79.2	83.9	88.5
64			54.5	59.5	64.5	69.5	74.5	79.5	84.5	89.4	94.3
66			58.2	63.4	68.6	73.9	79.2	84.5	89.7	95.0	100.0
68				67.2	72.9	78.5	84.0	89.6	95.2	100.8	106.4
70				71.3	77.2	83.2	89.2	95.0	101.0	106.9	112.9
72				75.3	81.6	87.9	94.2	100.5	106.7	113.0	119.3
74					86.2	92.8	99.5	106.0	112.6	119.3	126.0
76					91.0	98.0	105.0	112.0	119.0	126.0	133.0
78					96.0	103.1	110.6	118.0	125.3	132.8	140.1
80						108.6	116.4	124.1	132.0	139.6	147.5
82						114.2	122.4	130.5	138.6	146.8	155.0
84						119.8	128.3	136.8	145.5	154.0	162.6
86							134.3	143.2	152.1	161.1	170.1
88							140.5	150.0	159.3	168.7	178.1
90							147.0	156.6	166.5	176.5	186.3
92								164.1	174.5	184.6	195.0
94								171.0	182.0	192.5	203.5
96								178.8	190.0	201 0	212.3
98									198.3	210.0	222.0
100									206.0	218.0	230.0
102									214.4	227.0	240.0
104										236.0	249.2
106										247.5	259.0
108										255.0	269.0

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TABLE—(*Continued*).

Diam. of Wheel. Inches.	Width of Fan Wheel at Periphery. Inches.									
	40	42	44	46	48	50	52	54	56	58
64	99.2									
66	105.5									
68	112.0	117.6								
70	118.8	124.7								
72	125.6	131.9	138.1							
74	132.5	139.1	145.8							
76	140.0	147.0	154.0	161.0						
78	147.5	155.0	162.3	169.6						
80	155.2	163.0	170.7	178.5	186.2					
82	163.2	171.4	179.5	187.8	196.0	204.0				
84	171.1	179.7	188.2	196.8	205.3	214.0	222.5			
86	179.0	188.0	197.0	206.0	215.0	224.0	233.0	242.0		
88	187.5	196.8	206.1	215.5	225.0	234.3	243.6	253.0	262.2	
90	196.0	206.0	215.8	225.8	235.5	245.0	255.0	264.6	274.3	284.0
92	205.0	215.5	225.8	236.0	246.2	256.3	266.4	277.0	287.0	297.5
94	214.0	224.4	235.4	246.0	256.6	267.5	278.0	289.0	299.5	310.0
96	223.6	234.6	246.0	257.0	268.2	279.6	290.3	302.0	313.0	324.0
98	233.5	245.0	256.5	268.0	280.0	292.0	303.5	315.0	327.0	338.0
100	242.5	254.5	266.6	278.8	291.0	303.0	315.0	327.0	339.5	351.5
102	253.0	265.0	277.5	290.0	303.0	315.5	328.0	341.0	353.0	366.0
104	262.4	275.5	288.6	302.0	315.9	328.0	341.0	354.0	367.0	380.0
106	272.5	286.5	300.0	313.5	327.0	341.0	354.5	368.0	382.0	395.0
108	283.0	297.5	311.5	326.0	340.0	354.0	368.0	382.0	396.5	411.0

Horsepower Required to Drive Blowers.—The power required to drive an encased fan, or blower, may be found by multi-

Pressure. Ounces.	Corresponding Pressure. Inches.	Factors.	
		When $W = \frac{D}{2}$ Multiply D^2 by	When W is Less or More Than $\frac{D}{2}$ Multiply Blast Area ($\frac{DW}{3}$), in Square Inches, by
¼	.433	.0006	.0036
½	.866	.0018	.0108
¾	1.310	.0028	.0168
1	1.730	.0049	.0294

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plying the square of the diameter, or the square inches of blast area, as the case may require, by the accompanying factors, in which W is the width of blade and D the diameter of wheel.

Selection of Fans.—While the capacity of an encased fan varies directly with its speed, the power required varies as the cube of the speed; hence, as a rule, it will be found preferable to use a comparatively large fan and run it at a moderate speed.

This is particularly true where the motive power is electricity, gas, or water, but, in the case of an engine-driven fan, does not amount to much when the exhaust steam is utilized in heating the air. There are, however, other reasons why a large fan is preferable, particularly in public buildings and schools, as a lower speed may be maintained to move the same volume of air, thus reducing the vibration to a minimum. In mill work, where the hum of other machinery makes the vibration of the fan inaudible, it is customary to use comparatively small fans, producing high velocities. Should it be found preferable to use a type different from the ordinary encased fan, there are two alternatives: the disk, or propeller, fan and the cone fan. The former may be relied on under certain conditions, but when used in connection with a ventilating system, blowing air through pipes and over heating coils, it is not able to deliver air against any appreciable resistance. In selecting centrifugal fans, small wheels operated at high speed should be avoided. Large wheels waste less power and have the advantage of possessing a large reserve capacity, that may be brought into use by increasing the speed.

Efficiency of Fans.—The efficiency of a fan is obtained by dividing the power supplied by that usefully employed in moving the air. The efficiency varies with the pressure against which the fan works, the highest efficiency commonly being found under a back pressure of about 1 oz. Under ordinary working conditions an efficiency of 50 per cent. is as high as can be expected. The extreme limit of possible efficiency is about 75 per cent.

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HEATERS.

Condensation in Heaters.—The amount of steam condensed in hot-blast heaters varies with the velocity of the air and the number of coils over which the air passes. The deeper the heater is, the higher will be the temperature of the air and the less the condensation per square foot; also, the higher the velocity of the air passing through the heater, the greater will be the amount of condensation.

Under the conditions usually obtaining in practice, with an outside temperature of 20°, it would be necessary to make provision for about 1¼ lb. of water of condensation per sq. ft. of surface per hr.

It has been found, in practice, that as condensation takes place more rapidly on the first section of the heater, there is a tendency toward such a reduction of pressure therein as to cause the water of condensation to be held back in the first section by the greater steam pressure in the others. To obviate this difficulty, it has frequently been found necessary to increase the area of the steam inlet openings to the first section, or, in some cases, to make the first section entirely independent of the others.

Value of Heating Surface.—The first section of a hot-blast heater does about 40 per cent. of the work; the second, about 25 per cent.; the third, about 15; the fourth, about 10; the fifth, about 6; and the sixth section, about 4 per cent. Beyond this, the increase in temperature is slight. The average value of the heating surface for a velocity of 600 feet through coils, when one section is used, is about 8¼ B. T. U. per degree difference between the steam in the pipes and the incoming air, dropping to 7.3 B. T. U. with the addition of a second section; 6.6 B.T.U., for the addition of a third; 6 B.T.U., for the addition of a fourth; and 5.5 B. T. U., for the addition of a fifth section; after which the heat emitted remains constant at about the last-named amount. Thus, with a heater having four sections, with an air velocity of 600 ft. through the heater, with steam at 215°, and air at 10°, a difference of 205°, we would have $205 \times 6 = 1{,}230$ B. T. U. per hr. per sq. ft. of pipe surface.

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Heaters made up of pipes properly arranged will give, roughly, 1,500 to 2,500 B. T. U. per hr. per sq. ft. of surface during zero weather, according to the steam pressure, the arrangement of the pipes, and the velocity of the air flowing between them.

The approximate amount of heat transmitted, in B. T. U., per square foot of heating surface per degree difference in temperature between that of the steam and air entering the hot-blast heater is given in the following table:

HEAT TRANSMISSION IN HOT-BLAST HEATER.

Number of Rows of Pipes.	Velocity of Air in Feet per Minute,							
	360	600	720	960	1,200	1,800	2,400	3,600
	Heat Emitted per Square Foot of Surface per Degree Difference in Temperature.							
1	8.2	9.9	10.7	12.0	13.1	15.5	17.6	19.5
4	7.1	8.5	9.2	10.3	11.3	13.4	15.2	17.0
8	6.1	7.3	7.8	8.7	9.5	11.3	12.9	14.5
12	5.5	6.6	7.0	7.8	8.4	9.9	11.1	12.8
16	5.1	6.0	6.4	7.0	7.6	8.8	9.9	11.6
20	4.8	5.5	5.9	6.5	7.1	8.2	9.2	10.9
24	4.3	5.3	5.6	6.2	6.7	7.7	8.6	10.2

Heaters made up of ordinary cast-iron indirect pin-type radiators will not give off much more than half the heat per square foot of extended or rated surface that is given off per square foot of prime surface in regular 1″ pipe heaters; therefore, fan radiators for ordinary work should be rated to give off 1,000 to 1,500 B. T. U. per sq. ft. per hr., according to the steam pressure and velocity of the air flowing between the sections.

Size of Heater Compared With Direct Radiating Surface Required. A heater used in connection with a fan that takes its air supply from inside the building should give off 1,200 to

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1,500 B. T. U. per sq. ft. of heating surface per hr. This is a cheap way to heat large mills and factories.

Size of Heaters.—In any system, to maintain rooms at the standard temperature of 70°, there must be supplied an amount of heat sufficient to offset the transmission losses through the outside walls, windows, and roof, plus the accidental leakage, and outflow of air through the vent flues.

To compute heat losses and size of heaters, it is convenient, and sufficiently accurate for ordinary work, to consider 1 sq. ft. of glass surface as equivalent in heat-transmitting power to 4 sq. ft. of wall. Reduce the exposed wall and glass surface to equivalent glass surface by dividing the wall surface by 4 and add to this the actual glass surface. Compute the equivalent glass surface (E. G. S.) of each wall in this manner, then multiply by the following factors to compensate for the effect of winds: north, 1.25; south, 1.05; east, 1.15; west 1.25. Add to this the E. G. S. of roof, which is approximately equal to one-tenth of the roof area, and multiply the total E. G. S. by 85, the latter number representing the number of B. T. U. transmitted per hour per square foot of glass with a temperature of 70° inside and zero outside. The product is the number of B. T. U. transmitted per hour.

When the air supply is taken from the outside, the leakage of air from the building is commonly assumed to be equal to the air supply, the accidental leakage or ingress of air due to winds having been allowed for by the factors used in connection with the exposure.

With an inside temperature of 70° in zero weather, each cubic foot of air escaping from the building carries with it about 1¼ B. T. U. The volume escaping per hour, multiplied by 1¼, gives the heat loss by leakage. Adding the losses of heat by transmission and by leakage gives the total, which, divided by the heat emitted per square foot of heating surface, gives the size of the heater required.

It has been found, in practice, that with a steam pressure of, say, 80 lb. and air taken from outdoors, factories may be warmed successfully with heaters based on 1 lin. ft. of 1″ pipe to every 125 to 150 cu. ft. of space.

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If the air is used over and over, i. e., has internal circulation only, ratios of 1 to every 150 to 175 cu. ft. of space, according to the conditions, may be used. Even greater ratios are permissible with very large buildings.

Heaters will not condense more than two-thirds as much exhaust as live steam; this fact must be borne in mind.

In churches, where the heating is intermittent and the air change more frequent than in manufacturing buildings, an allowance of 1 lin. ft. of 1″ pipe to every 60 to 90 cu. ft. of space represents common practice.

In schools heated entirely by the blower system, each standard 50-pupil room of about 11,000 cu. ft. of space should have at least 300 ft. of 1″ pipe provided in the heater, giving a ratio of about 1 to 40. The large allowance for schoolrooms is due to the frequent air change, which must never be overlooked in proportioning heaters.

The free area between the heater pipes should be 50 per cent. greater than that of the fan outlet to insure a maximum velocity of 1,500 to 1,800 ft. per min.

When the total B. T. U. required is approximately 100 times the volume of air, in cubic feet per minute, as is frequently the case, a short method of determining the size of the heater required is to divide the volume of air per minute by 15 for low-pressure steam, or by 23 for steam at 80 lb.

For heating and ventilating schools, churches, and public buildings, an area between the pipes that will permit an air velocity of from 900 to 1,200 ft. per min. will be found satisfactory. In factory heating an air velocity of from 1,500 to 1,800 ft. per min. is not excessive.

Sizes of Steam Pipes to Supply Heaters.—Since the water of condensation from heaters is generally trapped to a receiver and not returned directly to the boiler, a considerable drop in the pressure of the steam in passing through the supply pipe may be assumed, and on that account the pipe may be made much smaller than would be necessary with a gravity return to the boiler. When the heater is within 100 ft. of the boiler, the pipe sizes are given in the table headed "Trap-Discharge Pipes for Heaters."

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TRAP-DISCHARGE PIPES FOR HEATERS.

Lineal Feet of 1″ Pipe in Heater.	Size of Steam Pipe.	Size of Return Pipe.
1,000 or Less	1¼	1
1,000–2,000	2	1¼
2,000–3,000	2½	1½
3,000–4,000	3	1½
4,000–5,000	3½	2
5,000–6,000	4	2

For gravity-return systems with but little difference in level between the water-line in the boiler and the return connection of the heater, the pipe sizes should be as follows:

PIPE SIZES FOR HEATERS WITH GRAVITY RETURN.

Lineal Feet of 1″ Pipe in Heater.	Supply.	Return.
1,000 or Less	3½	2½
1,000–2,000	4	3
2,000–3,000	5	3
3,000–4,000	6	3
4,000–5,000	7	3½
5,000–6,000	8	4

In proportioning heaters to condense the exhaust from main engines, not less than 75 lin. ft. of 1″ pipe per H. P. should be provided. The supply connections should not be smaller than 3 in. up to 30 H. P., 4 in. for 30 to 50 H. P., 5 in. for 50 to 80 H. P., 6 in. for 80 to 120 H. P., 7 in. for 120 to 160 H. P., and 8 in. for 160 to 220 H. P.

DUCTS AND FLUES.

Theoretical Area of Ducts and Flues.—The size of the ducts from the fan or heater to vertical flues, as well as the size of the latter, depend on the velocity with which the air flows through them.

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With the blow-through type of fan-heating system, the main air duct, directly on leaving the mouth or outlet of the heater, is expanded so as to make its area from 25 to 50 per cent. greater than that of the fan outlet, in order to reduce the velocity of the air and to insure a large volume with the least possible resistance.

DUCT AND FLUE SIZE FACTORS BASED ON AIR SUPPLY.

Velocity. Feet per Minute.	Air Supply per Person per Hour.						
	900	1,000	1,200	1,500	1,800	2,000	2,400
	Air Supply per Person per Minute.						
	15	16.6	20	25	30	33.3	40
300	7.20	8.00	9.60	12.00	14.40	16.00	19.20
400	5.40	6.00	7.20	9.00	10.80	12.00	14.40
500	4.32	4.80	5.76	7.20	8.64	9.60	11.52
600	3.60	4.00	4.80	6.00	7.20	8.00	9.60
700	3.10	3.43	4.12	5.14	6.20	6.86	8.24
800	2.70	3.00	3.60	4.50	5.40	6.00	7.20
900	2.40	2.66	3.20	4.00	4.80	5.32	6.40
1,000	2.16	2.40	2.88	3.60	4.32	4.80	5.76
1,200	1.80	2.00	2.40	3.00	3.60	4.00	4.80
1,500	1.44	1.60	1.92	2.40	2.88	3.20	3.84
1,800	1.20	1.33	1.60	2.00	2.40	2.66	3.20
2,000	1.08	1.20	1.44	1.80	2.16	2.40	2.88
2,400	.90	1.00	1.20	1.50	1.80	2.00	2.40

By using the above table, the area of ducts and flues, in square inches, neglecting friction, is found by multiplying the number of occupants by the tabulated factors corresponding to the amount of air to be supplied, per hour, at the desired velocity in feet per minute.

The factors given in the table were obtained by means of the formula

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$$A = \frac{2.4\,S\,N}{V}$$

in which A = area of duct or flue, in square inches;
S = air supply, in cubic feet per hour per person;
N = number of occupants;
V = velocity, in feet per minute.

The factors given are for conditions under which $N = 1$. For example, $S = 1{,}800$, $N = 1$, $V = 900$; then,

$$A = \frac{2.4 \times 1{,}800 \times 1}{900} = 4.8, \text{ the tabulated factor.}$$

The required coefficient for any velocity and air supply not given in the table may be found easily by applying the formula given.

When the air velocity in ducts and flues in feet per second, the number of air changes per hour, and the size of the room are given, the required duct or flue area in square inches, friction neglected, can be found by multiplying the factor corresponding to the air velocity and the number of air changes taken from the table "Duct and Flue Size Factors Based on Air Changes," by the contents of the room in cubic feet.

DUCT AND FLUE SIZE FACTORS BASED ON AIR CHANGES.

Velocity. Feet per Second.	Number of Air Changes per Hour.								
	2	3	4	5	6	7	8	9	10
10	.0080	.0120	.0160	.0200	.0240	.0280	.0320	.0360	.0400
15	.0053	.0080	.0106	.0133	.0160	.0186	.0213	.0240	.0266
20	.0040	.0060	.0080	.0100	.0120	.0140	.0160	.0180	.0200
25	.0032	.0048	.0064	.0080	.0096	.0112	.0128	.0144	.0160
30	.0026	.0040	.0053	.0066	.0080	.0093	.0106	.0120	.0133
35	.0023	.0034	.0046	.0057	.0068	.0080	.0091	.0102	.0114
40	.0020	.0030	.0040	.0050	.0060	.0070	.0080	.0090	.0100
45	.0018	.0026	.0035	.0044	.0053	.0062	.0071	.0080	.0089
50	.0017	.0024	.0032	.0040	.0048	.0056	.0064	.0072	.0080

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FLUE AREA, IN SQUARE INCHES, FOR 1,000 CUBIC FEET.

(B. F. Sturtevant Company.)

Number of Minutes to Change Air.	Velocity of Air in Flue in Feet per Minute.												
	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
4	120.0	90.0	72.0	60.0	51.6	45.0	40.0	36.0	32.2	30.0	27.6	25.6	21.4
5	96.0	72.2	57.6	48.0	41.1	36.1	32.0	28.8	26.2	24.0	22.2	20.5	19.2
6	80.0	60.0	48.0	40.0	34.3	30.0	26.6	24.0	21.8	20.0	18.5	17.1	16.0
7	68.6	51.4	41.1	34.3	29.4	25.7	22.9	20.6	18.7	17.2	15.7	14.7	13.7
8	60.0	45.0	36.0	30.0	25.8	22.5	20.0	18.0	16.1	15.0	13.8	12.8	12.0
9	53.3	40.0	32.0	26.6	22.9	20.0	17.8	16.0	14.5	13.3	12.3	11.4	10.7
10	48.0	36.0	28.8	24.0	20.6	18.0	16.0	14.4	13.1	12.0	11.1	10.3	9.6
11	43.6	32.2	26.2	21.8	18.7	16.1	14.5	13.1	11.9	10.9	10.1	9.5	8.7
12	40.0	30.0	24.0	20.0	17.2	15.0	13.3	12.0	10.9	10.0	9.2	8.6	8.0
13	36.9	27.7	22.2	18.5	15.7	13.8	12.3	11.1	10.1	9.2	8.5	7.9	7.4
14	34.3	25.7	20.6	17.2	14.7	12.8	11.4	10.3	9.5	8.6	7.9	7.4	6.9
15	32.0	24.0	19.2	16.0	13.7	12.0	10.7	9.6	8.7	8.0	7.4	6.9	6.4
16	30.0	22.5	18.0	15.0	12.9	11.2	10.0	9.0	8.2	7.5	6.9	6.4	6.0
17	28.2	21.2	16.9	14.1	12.1	10.6	9.4	8.5	7.7	7.0	6.5	6.1	5.6
18	26.6	20.0	16.0	13.3	11.5	10.0	8.9	8.0	7.3	6.6	6.2	5.7	5.3
19	25.3	18.9	15.2	12.6	10.8	9.5	8.4	7.6	6.9	6.3	5.8	5.4	5.1
20	24.0	18.0	14.4	12.0	10.3	9.0	8.0	7.2	6.5	6.0	5.5	5.1	4.8

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The B. F. Sturtevant Company presents the preceding table for obtaining the flue area, in square inches, when the number of minutes required for one air change, the velocity of air desired in the flue in feet per minute, and the size of the room are given. To apply the table, divide the contents of the room, in cubic feet, by 1,000, and multiply the quotient by the factor in the table corresponding to the time of air change and the desired air velocity.

The number of round branch pipes that have the same air-carrying capacity as a round main blast pipe of a given diameter is given in the table "Number of Branches Supplied by Main Blast Pipes." In this table, allowance has been made for the friction of pipes smaller in diameter than the main blast pipe. Thus, sixteen 3″ pipes will have the same cross-sectional area as one 12″ pipe; owing to the excessive frictional resistance of the small pipes, thirty-two pipes 3 in. in diameter will, in practice, as shown by the table, have the same carrying capacity as one 12″ pipe. In some cases, the number representing the number of branch pipes equivalent to a given main pipe is a whole number and a fraction; thus, 5.7 two-inch pipes are given as equivalent to one 4″ pipe. In practice, the nearest whole number of pipes must be selected, as a fractional number of pipes is an impossibility.

Allowance for Frictional Resistance.—To counteract the effect of drop in pressure and reduction in velocity due to frictional resistance when air is carried through piping of different lengths, it is necessary to increase the area of the pipe according to the distance to which the air is to be transmitted. In other words, to supply a given amount of air at a distance from the fan, the area of the pipe should be increased by multiplying the area of the outlet through which the given quantity of air would be discharged at the given initial velocity, by the factors given in the table "Factors for Duct and Flue Area Increase." For example, it is desired to supply 2,000 cu. ft. of air per min. at a distance of 360 ft. from the fan, the initial velocity at the latter being 3,670 ft. per min. at 1″ pressure, corresponding to the delivery capacity of a 10″ pipe. The area of a 10″ pipe being 78.54 sq. in., and the area

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NUMBER OF BRANCHES SUPPLIED BY MAIN BLAST PIPES.

Diameter of Main Blast Pipe. In.	Diameter of Branch Pipe. Inches.																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22
3	16.0	2.7																			
4	32.0	5.7	2.0																		
5	56.0	9.8	3.6	1.8																	
6	88.0	16.0	5.7	2.8	1.6																
7	129.0	23.0	8.3	4.1	2.3	1.5															
8	180.0	32.0	12.0	5.7	3.2	2.1	1.4														
9	244.0	42.0	16.0	7.6	4.3	2.8	1.9	1.3													
10	317.0	56.0	20.0	9.9	5.7	3.6	2.4	1.7	1.3												
11	402.0	71.0	26.0	12.0	7.0	4.5	3.1	2.2	1.7	1.3											
12	501.0	88.0	32.0	16.0	9.0	5.7	3.8	2.8	2.0	1.6	1.2										
13	613.0	107.0	39.0	19.0	11.0	6.9	4.7	3.4	2.5	1.9	1.5	1.2									
14	737.0	129.0	47.0	23.0	13.0	8.3	5.7	4.1	3.0	2.3	1.8	1.5	1.2								
15	876.0	152.0	56.0	27.0	16.0	9.9	6.7	4.8	3.6	2.8	2.2	1.8	1.4	1.2							
16	1,026.0	180.0	65.0	32.0	18.0	11.0	7.9	5.7	4.2	3.2	2.6	2.1	1.7	1.4	1.2						
17	1,197.0	208.0	76.0	37.0	21.0	13.0	9.2	6.6	4.9	3.8	2.9	2.4	2.0	1.6	1.4	1.2					
18	1,375.0	239.0	88.0	43.0	24.0	16.0	10.0	7.7	5.7	4.3	3.4	2.8	2.3	1.9	1.6	1.3	1.2				
19	1,580.0	275.0	100.0	49.0	28.0	18.0	12.0	8.8	6.5	5.0	3.9	3.2	2.6	2.2	1.8	1.5	1.3	1.2			
20	1,797.0	313.0	114.0	56.0	32.0	20.0	14.0	9.9	7.4	5.7	4.5	3.6	2.9	2.5	2.1	1.7	1.5	1.3	1.4		
22	2,284.0	398.0	145.0	71.0	41.0	26.0	18.0	13.0	9.3	7.2	5.7	4.5	3.7	3.1	2.6	2.2	1.9	1.7	1.4	1.3	
24	2,834.0	493.0	180.0	88.0	50.0	32.0	22.0	16.0	12.0	8.9	7.6	5.7	4.6	3.8	3.2	2.9	2.4	2.1	1.8	1.6	1.2
26	3,474.0	605.0	219.0	108.0	62.0	39.0	27.0	19.0	14.0	11.0	8.6	6.9	5.7	4.7	4.0	3.4	2.9	2.5	2.2	1.9	1.5
28	4,165.0	725.0	265.0	129.0	74.0	48.0	32.0	23.0	17.0	13.0	10.0	8.3	6.8	5.7	4.8	4.1	3.5	3.0	2.6	2.3	1.8
30	4,963.0	864.0	315.0	154.0	88.0	56.0	38.0	28.0	20.0	16.0	12.0	9.9	8.0	6.7	5.7	4.7	4.1	3.6	3.0	2.6	2.2
36	7,818.0	1,361.0	497.0	243.0	139.0	88.0	60.0	43.0	32.0	25.0	19.0	16.0	13.0	11.0	8.9	7.6	6.5	5.7	5.0	4.3	3.4
42	11,488.0	2,000.0	730.0	358.0	205.0	129.0	88.0	63.0	47.0	36.0	29.0	23.0	19.0	16.0	13.0	11.0	9.6	8.5	7.3	6.4	5.0
48	15,989.0	2,792.0	1,081.0	492.0	282.0	180.0	123.0	88.0	66.0	50.0	39.0	32.0	26.0	22.0	18.0	16.0	13.0	12.0	10.0	8.9	7.0
54	21,560.0	3,753.0	1,368.0	671.0	384.0	244.0	166.0	119.0	88.0	68.0	53.0	43.0	35.0	29.0	24.0	21.0	18.0	16.0	15.0	12.0	9.4
60	27,913.0	4,879.0	1,781.0	872.0	499.0	314.0	215.0	154.0	115.0	88.0	69.0	56.0	46.0	38.0	32.0	27.0	23.0	20.0	18.0	16.0	12.0
66	35,300.0	6,349.0	2,300.0	1,090.0	630.0	399.0	273.0	197.0	147.0	110.0	88.0	70.0	58.0	48.0	40.0	34.0	29.0	25.0	22.0	20.0	16.0
72	43,740.0	7,900.0	2,820.0	1,370.0	815.0	500.0	339.0	243.0	181.0	142.0	115.0	90.0	72.0	60.0	50.0	43.0	37.0	32.0	28.0	24.0	19.0

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TABLE—(*Continued*).

Diameter of Main Blast Pipe. In.	Diameter of Branch Pipe. Inches.								
	24	26	28	30	36	42	48	54	60
26	1.2								
28	1.5	1.2							
30	1.7	1.4	1.2						
36	2.7	2.2	1.9	1.6					
42	4.1	3.3	2.8	2.3	1.5				
48	5.7	4.7	3.8	3.2	2.1	1.4			
54	7.6	6.2	5.2	4.3	2.8	1.9	1.3		
60	9.9	8.1	6.7	5.7	3.6	2.4	1.8	1.3	
66	12.0	10.0	8.5	7.1	4.5	3.1	2.2	1.6	1.3
72	15.0	12.0	10.0	8.9	5.6	3.8	2.7	2.1	1.6

factor 3.4, the required area will be, approximately, $3.4 \times 78.54 = 267$ sq. in., and the corresponding velocity of the flow will be $\frac{3,670}{3.4} = 1,079$ ft. per min. The frictional resistance offered by the piping to the passage of air therein depends on the extent of the surface with which the air comes in contact, being directly proportional to the length and inversely to the diameter of the pipe, also varying as the square of the velocity of the moving air.

FACTORS FOR DUCT AND FLUE AREA INCREASE.

Length of Pipe. Feet.	Area Factor.	Length of Pipe. Feet.	Area Factor.
Fan Outlet	1.0	210	2.4
30	1.2	240	2.6
60	1.4	270	2.8
90	1.6	300	3.0
120	1.8	330	3.2
150	2.0	360	3.4
180	2.2	390	3.6

With carefully made galvanized-iron pipe, erected with all internal laps extending in the direction of the air movement,

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practical use may be made of the following formulas, in which

p = loss of pressure, in ounces per square inch;
v = velocity of air, in feet per second;
l = length of pipe, in feet;
d = diameter of pipe, in inches.

$$p = \frac{l v^2}{25{,}000\, d}.$$

$$v = \sqrt{\frac{25{,}000\, d\, p}{l}}.$$

$$l = \frac{25{,}000\, p\, d}{v^2}.$$

$$d = \frac{l v^2}{25{,}000\, p}.$$

The horsepower lost in friction in a pipe 100 ft. long may be expressed by the formula

$$\text{H. P.} = \frac{p\, a\, v}{8{,}800};$$

wherein a is area of pipe, in square inches, and the other letters have the same meaning as in the previous formulas.

Resistance of Bends.—The resistance caused by bends in the piping may be approximately determined by using the

FRICTIONAL RESISTANCE OF ELBOWS.

Inner Radius of Elbow in Diameters of Pipe.	Resistance of Elbow in Equivalent Length of Straight Pipe, in Diameters of Pipe.
6	10
5	12
4	16
3	20
2	28
1½	36
1	54
¾	80
½	120

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factors given in the table "Frictional Resistance of Elbows," which gives the resistance of elbows in equivalent lengths of straight pipe, expressed in terms of the pipe diameter. For example, the resistance offered by an elbow having an inner radius of 2 diameters will, approximately, be the same as that of a straight piece of the pipe 28 diameters in length. The necessity of avoiding short-radius bends is made apparent by the tabulated figures, which show that the resistance increases rapidly as the inner radius of the bend decreases.

Air Velocities.—Experience has shown that for flues in the walls of such buildings as schools, churches, office buildings etc., a flue velocity from 500 to 800 ft. per min., with a corresponding velocity through registers into rooms of from 250 to 600 ft. per min., and a floor-register velocity of 300 ft. per min., are desirable. Velocities of from 1,800 to 2,500 ft. per min. are customary in the main air duct. The branch ducts to flues should be figured at velocities of from 1,000 to 1,500 ft. per min., depending on their distances from the fan. The intermediate main ducts should be proportioned for velocities gradually reducing from that in the main duct near the fan to 1,000 to 1,500 ft. at the extreme ends, the extreme end being taken as a branch duct. Except in cases of great lengths of pipe and a multiplying of elbows and turns, the lesser velocity of the extremes given above should be used. The velocities for factory buildings may be practically twice those given above.

Capacity of Natural-Draft Vent Ducts.—The quantity of air, in cubic feet per minute, discharged by a ventilating duct 1 sq. ft. in area, under different conditions, with an external air temperature of 32° F., is given in the table "Ventilating-Duct Capacity." The quantity of air discharged by ventilating flues having an area other than 1 sq. ft. may be found by multiplying the discharge taken from the table by the area of the ventilating flue in square feet.

The amount of air discharged when the external temperature is above 32° may be obtained approximately by using the tabulated factors corresponding to the difference between the internal and external temperatures.

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VENTILATING-DUCT CAPACITY.

Height of Vent Duct. Feet.	Excess of Temperature of Air in Vent Duct, Above That of External Air.								
	5°	10°	15°	20°	25°	30°	50°	100°	150°
10	77	108	133	153	171	188	242	342	419
15	94	133	162	188	210	230	297	419	514
20	108	153	188	217	242	265	342	484	593
25	121	171	210	242	271	297	383	541	663
30	133	188	230	265	297	325	419	593	726
35	143	203	248	286	320	351	453	640	784
40	153	217	265	306	342	375	484	682	838
45	162	230	282	325	363	398	514	722	889
50	171	242	297	342	383	419	541	759	937

Weight of Piping.—In estimating the weight of the round, galvanized-iron pipes that are commonly used for the ducts and flues of blower systems, the accompanying table, by the E. M. Link Machinery Company, will be found convenient, as the weights therein given represent the weight of the pipes made up complete, proper allowance having been made for laps and trimmings. The elbows have an inner radius equal to the diameter of the pipe. Owing to the variations in the thickness of the material, galvanizing, etc., the weights given in the table are not absolutely exact, but are sufficiently accurate for all practical purposes.

The weight of rectangular pipes is best obtained by first finding the surface of the pipe, in square feet, and multiplying this by the weight of the iron, in pounds per square foot, corresponding to the gauge number, as given in the table "Weight of Galvanized Sheet Iron."

Ducts and flues of galvanized iron should not, as a rule, be lighter than the following gauges: No. 28, for pipes under 8 in. in diameter; No. 26, for pipes 8 in. to 12 in.; No. 24, for pipes 13 in. to 18 in.; No. 23, for pipes 19 in. to 24 in.; No. 22, for pipes 25 in. to 30 in.; No. 20, for pipes 31 in. to 40 in.; No. 18, for pipes 41 in. to 50 in.; No. 16, for pipes 51 in. to 60 in.

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WEIGHT OF ROUND, GALVANIZED-IRON PIPE, IN POUNDS PER RUNNING FOOT.

Diameter of Pipe. Inches.	Gauge of Iron.						
	No. 28.	No. 26.	No. 24.	No. 22.	No. 20.	No. 18.	No. 16.
4	1	1 1/8	1 1/4	1 3/4	2 1/8	2 5/8	3 1/4
5	1 1/4	1 3/8	1 5/8	2 1/8	2 5/8	3 1/4	3 7/8
6	1 1/8	1 5/8	1 7/8	2 5/8	3 1/8	3 3/4	4 3/8
7	1 5/8	1 7/8	2 1/8	3	3 1/2	4 3/8	5 1/8
8	1 7/8	2 1/8	2 3/8	3 3/8	4	5	6 1/8
9	2 1/8	2 3/8	2 3/4	3 3/4	4 1/2	5 1/8	6 7/8
10	2 3/8	2 5/8	3	4 1/8	5	6 1/4	7 1/8
11	2 1/8	3	3 3/8	4 1/2	5 1/2	6 3/4	8 1/8
12	2 3/4	3 1/4	3 3/8	5	6	7 1/4	9
13		3 1/8	3 7/8	5 1/4	6 1/8	7 7/8	9 3/4
14		3 3/4	4 1/4	5 3/4	7	8 1/8	10 1/8
15		4	4 1/8	6 1/4	7 1/8	9 1/8	11 1/4
16		4 1/4	4 3/4	6 5/8	8	9 5/8	12
17		4 1/8					
18		4 3/4	5 1/8	7 1/8	9	10 7/8	13 1/8
20			6	8 1/4	10	12 1/8	15
22				9	11	13 3/8	16 1/8
24				9 7/8	12	14 1/8	18
26				10 3/4	13	15 5/8	19 1/8
28				11 1/8	14	17	21
30				12 1/8	15	18 1/4	22 5/8
32					16	19 1/8	24
34					17	20 3/4	25 1/8
36					18	22	27
38					19	23	28 1/8
40					20	24 1/4	30
42					21	25 1/8	31 1/8
44					22	26 1/8	33
46					23	28	34 1/8
48					24	29	36
50					25	30	37 1/8
52					26	31 1/8	39
54					27	33	40 1/8
56					28	34	42
58					29	35	43 1/8
60					30	36 1/8	45

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WEIGHT OF GALVANIZED SHEET IRON.

Gauge Number.	Weight per Square Foot. Pounds.	Gauge Number.	Weight per Square Foot. Pounds.
16	2.7	24	1.2
18	2.2	26	.9
20	1.7	28	.8
22	1.4		

TEMPERATURE REGULATION.

The temperature-controlling systems commonly employed with blower systems are automatic in operation. With such a system of control, it is simply necessary for the engineer to supply the heating system with sufficient steam. The thermostats regulate the temperature within 2° above or below that for which they are set.

The controlling apparatus usually installed consists of thermostats located in the rooms and connected by small air pipes to the valves or radiators and heaters, or to mixing dampers. The thermostats, operated by differences in temperature, alternately admit compressed air to and release it from the pipes. An air pressure of about 15 lb. is automatically maintained on the system by a pump or air compressor.

The air pressure at hand should also be used to operate remote dampers in heating ducts and vent flues, the actuation of the damper being effected by turning a valve on a switchboard conveniently located in the basement.

One of the best methods of arranging the temperature control of a building equipped with a blower ventilating system, in connection with which the heating is largely done by direct radiation, is to use diaphragm radiator valves that automatically shut off the steam from the radiators when the temperature of the room rises to 70°, or to whatever point the thermostat may be set.

The temperature of the air supply is kept at or near 70° by cold-air and warm-air thermostats. The one placed in the

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cold-air room or duct is connected with the steam valves on a portion of the main heater, so that when the outdoor temperature rises above a certain point, and steam is no longer needed, it is automatically shut off.

The warm-air thermostat placed in the duct beyond the fan shuts off the balance of the heater when no longer needed. This thermostat alternately closes and opens the steam valves.

By-pass dampers are also used to by-pass cold air when the regulation of the temperature must be very close.

Supplementary heaters at the base of flues, when used in place of direct radiators in the rooms, are connected with the room thermostats, which permit the tempered air from the blower to flow through the supplementary heaters without being reheated when the rooms do not require heat; or, the supplementary heaters may be supplied with mixing dampers.

With a single duct system, the thermostats are made to operate the register blades or the damper in the pipes, controlling the temperature by cutting down the air supply.

DRYING AND COOLING AIR.

To make assembly rooms comfortable in hot weather the air forced into the rooms by the fan must not only be cooled, but its humidity must be kept within reasonable limits. In order to give the air an agreeable feeling of freshness, its humidity must be reduced to 40 per cent., or less. The regulation of the humidity of the cooled air may be accomplished in several ways.

1. The air may be cooled to a temperature considerably below that at which it is desired to admit it to the rooms, the moisture in the air being condensed and the air then warmed slightly to reduce the relative humidity.

2. A portion of the air may be heated as in (1), then be mixed with untreated air by-passed around the refrigerating coils or ice box; the proportion of the two being regulated to effect the desired result.

3. The air after being cooled may be passed over shallow trays containing calcium chloride, which is capable of absorbing about three times its own weight of moisture.

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GAS AND GAS-FITTING.

GAS.

KINDS OF GAS.

Coal gas is made by heating bituminous coal in air-tight boxes or retorts. The heat breaks up the combinations of hydrogen and carbon in the coal, transforming them into other compounds, most of which are gaseous at ordinary temperatures. Among the new compounds thus made are tar, ammonia, and sulphureted hydrogen. The tar and ammonia are condensed and removed. The gas also undergoes purification and scrubbing; in the former process, the gas is forced in thin streams through pans filled with lime, oxide of iron, etc.; and in the latter, through bodies of liquid charged with certain chemicals.

Oil gas is made from petroleum in a similar way and from almost any kind of oil, grease, or fat.

Producer gas differs from the coal gas commonly used for lighting, in having much less combustible matter, and in having a large percentage of nitrogen. It is made by burning anthracite or bituminous coal in a closed furnace, with a supply of air too small for complete combustion. The average quality of producer gas contains from 10 to 15 per cent. of hydrogen, from 20 to 30 per cent. of carbon monoxide (*CO*), and from 40 to 60 per cent. of nitrogen. Producer gas burns with a dull reddish flame, and its heating value is about one-fourth that of good coal gas.

Water gas is made from anthracite coal and steam. The coal is placed in an air-tight cylinder, ignited, and raised to an incandescent heat by an air blast; the blast is then shut off, and dry steam is blown through the glowing fuel. The intense heat breaks up the steam into free oxygen and hydrogen, the oxygen combining with the hot carbon, forming *CO*, and the hydrogen passing along with it, but not combining. These are then led to a gas holder. The operations of blowing up and making gas alternate at intervals of about

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3 minutes, until the fuel is exhausted. The fresh gas burns perfectly in heating burners, but when used for lighting purposes, is always enriched in carbon, by the vaporization of petroleum before it leaves the generator. The density of pure water gas is .4 that of air. It naturally has very little odor, but some impurities are allowed to remain to give the gas a perceptible odor.

Acetylene (chemical symbol, C_2H_2) is composed of 12 parts of carbon to 1 of hydrogen by weight, or 92.3 per cent. carbon and 7.7 per cent. hydrogen. It is the most brilliant illuminating gas known. Its density is about .91, and its weight at 32° F. is .073 lb. per cu. ft. It is without color, and has a strong odor, like garlic. It is poisonous to breathe, in about the same degree as ordinary gas. The heat developed by the combustion of 1 cu. ft. is theoretically 1,385 heat units. Acetylene is manufactured by mixing calcium carbide with water. The carbide is a mixture of coke and lime which had been fused in an electric furnace. It is reddish brown, or gray, in color, somewhat crystalline, and decomposes water like ordinary quicklime; the calcium takes oxygen from the water, forming oxide of calcium, or common quicklime, while the carbon combines with the hydrogen of the water, and forms the desired compound, acetylene. Considerable heat is given off during the operation.

Pure carbide of calcium will yield 5.4 cu. ft. of acetylene per pound; but it is hardly safe to reckon upon more than 4.5 cu. ft. from the commercial carbide. Special burners are required for acetylene illumination, provided with small air holes to supply more air to the flame than is obtained by ordinary burners. Acetylene will give a light of about 240 candlepower when burned at the rate of 5 cu. ft. per hour, while good coal gas only gives 16 candlepower at the same rate of combustion. Acetylene can be reduced to liquid form, at a temperature of 60°, by a pressure of about 600 lb. per sq. in., but is then unsuitable for use in buildings, owing to the danger of explosion. Acetylene corrodes silver and copper, forming explosive compounds, but does not affect brass, iron, lead, tin, or zinc. These facts should be borne in mind when constructing apparatus for its use.

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Gasoline gas, or *carbureted air*, sometimes called *air gas*, is a mixture of gasoline vapor with air, and, when pure, is so rich in carbon that special burners must be employed for lighting purposes. The quantity required to produce 1,000 cu. ft. of gas of from 14 to 16 candlepower is about 4½ gal. of the best grade, and more if the gasoline is of a lower grade. The specific gravity of gasoline is about .74 that of water. The temperature of a gasoline-gas machine should range between 40° to 80°. The highest grade of gasoline, that is, the grade that will evaporate most freely at ordinary temperatures, should be used for winter service. The generators should be located outside the building, in a sheltered place. An air pump is used to pump fresh air through the generator, and a mixing device is commonly employed for mixing air with the gas before it reaches the burners. The pump and mixer are usually located in the cellar of the building.

PRESSURE OF GAS.

If a gas is lighter than air, at the same temperature, the pressure will be greatest at the top of the chamber containing the gas; if heavier, the greatest pressure will be at the bottom of the chamber. The upward pressure of gas having a less density than air is caused by its deficiency in weight, and consequent inability to balance the pressure of the atmosphere.

For illustration, consider a column of gas 1 ft. square and 100 ft. high, having a density of .5, or one-half that of air, the temperature being the same as that of the atmosphere—say 60°. Air at 60° weighs .0764 lb. per cu. ft., and as the column contains 100 cu. ft., it will weigh $.0764 \times 100 = 7.64$ lb. The gas having a density of .5 will weigh only half as much, or 3.82 lb., and is, therefore, unable to balance an equal volume of air. Consequently, it is pressed upwards with a force of $7.64 - 3.82 = 3.82$ lb. against the top of the chamber which contains it. Whatever the actual pressure of the gas may be at the bottom of the column, it will, in this case, be increased at the top to the extent of 3.82 lb. per sq. ft.

The increase of pressure in each 10 ft. of rise in the pipes, with gas of various densities, is shown in the following table:

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Rise in pressure (in. of water)	0.	.0147	.0293	.044	.058	.073	.088	.102
Density of gas	1.	.9	.8	.7	.6	.5	.4	.3

EXAMPLE.—The pressure in the basement, at the meter, is 1.2 in. of water; what will be the pressure on the sixth story, 70 ft. above, the density of the gas being .4?

SOLUTION.—The table shows that the increase will be .088 for each 10 ft. of rise; therefore, $.088 \times 7 = .616$ increase. Then pressure at sixth story $= 1.2 + .616 = 1.816$ in.

MEASUREMENT OF PRESSURE AND FLOW.

Pressure.—The pressure of gas is measured by the common water gauge, which is shown in Fig. 1. The tubes *b* and *c* are glass, and are filled with water up to the zero of the scale, which is graduated in inches and fifths or tenths of an inch. The tube *c* is opened to the air at the top. When pressure is admitted to *a*, the water will sink in the tube *b*, and will rise in *c*. The difference in the height of the water in the two tubes, measured in inches, is the measure of the pressure exerted in *inches of water*. For measuring heavier pressures, mercury is used instead of water.

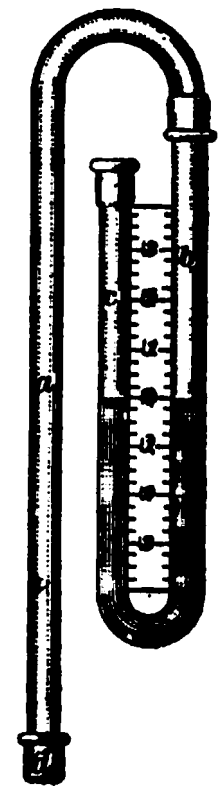

FIG. 1.

Pressures measured in inches of water or mercury may be translated into pounds per square inch or square foot, by multiplying the reading by the following figures:

1 in. of water at 62° F. = 5.2020 lb. per sq. ft.
1 in. of water at 62° F. = .0362 lb. per sq. in.
1 in. of mercury 62° F. = .4897 lb. per sq. in.

Pressure per square inch or square foot may be converted into inches or feet of water, or inches of mercury, by multiplying the pressures by the following figures:

1 lb. per sq. ft. = .1923 in. of water at 62° F.
1 lb. per sq. in. = 27.70 in. of water at 62° F.
1 lb. per sq. in. = .2042 in. of mercury at 62° F.

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Flow.—The volume of gas, passing through a pipe in a given time, is computed by multiplying the velocity by the area of the pipe. The velocity may be measured by a Pitot tube, as shown in Fig. 2. This consists of two tubes, *a* and *b*, inserted in a plug *c*, the lower end of *a* being square, and that of *b* curved to face the current; the upper ends are connected to a water gauge *d*. Gas entering through *b* depresses the water column as shown; the velocity corresponding to the reading is found from tables which are generally furnished with the instrument.

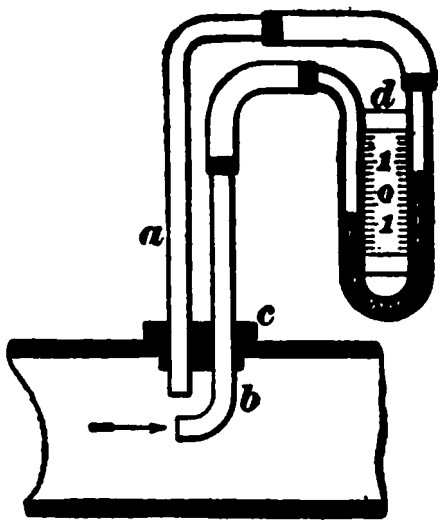

FIG. 2.

The actual quantity of the gas is computed by correcting the volume for temperature and pressure, reducing it to a volume at standard temperature of 32° F. and standard pressure of 1 in. of water. The correction for temperature may be made as follows:

Rule 1.—*Multiply the measured volume by 492 and divide the product by 460 plus the actual temperature. The quotient will be the volume at 32° F.*

The correction for pressure may be made as follows:

Rule 2.—*Multiply the volume at 32° F. by the pressure in inches of water plus 407, and divide the product by 408. The quotient will be the volume at 1 inch pressure, and at 32° F.*

EXAMPLE.—A pipe passes 1,000 cu. ft. of gas per hour, under a pressure of 8 in. of water and at a temperature of 60°. What will the volume be when the pressure is reduced to 1 in., and the temperature to 32°?

SOLUTION.—By the first rule, the volume at 32° is

$$\frac{1{,}000 \times 492}{460 + 60} = 946.1 \text{ cu. ft.}$$

By rule 2, the volume under 1 in. pressure and at 32° is

$$\frac{946.1 \times (8 + 407)}{408} = 962.3 \text{ cu. ft.}$$

If the quantity of gas delivered through a pipe of given

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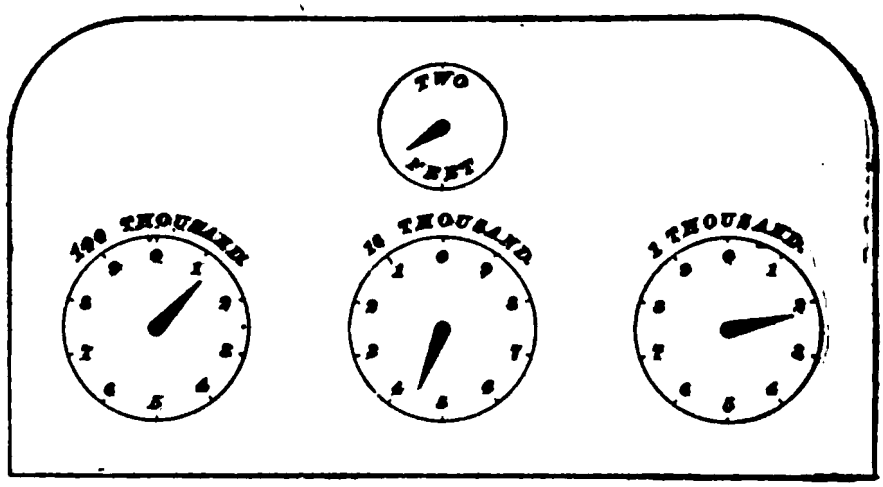
length is known, that supplied through a longer or shorter pipe is to the known volume as the square root of the given length is to the square root of the required length. With pipes of the same length and diameter, the volume delivered at any proposed pressure is to that supplied at any other pressure as the square root of the proposed pressure is to the square root of the given pressure.

GAS METERS AND PRESSURE REGULATORS.

Meters.—For ordinary purposes, the volume of gas passing through a pipe is measured by an apparatus called a *gas meter*. A gas meter measures the volume only, and its indications are not affected by any change that may occur in the pressure of the gas. The difficulty thus encountered in correctly measuring the volume of gas actually delivered under varying



pressures is overcome by using a governor between the meter and the street main, or service pipe. The governor is a species of reducing valve which will receive gas at any pressure, whether steady or variable, and will discharge it at a steady low pressure.

The illustration shows an ordinary meter. To read such a meter, note the lesser of the two figures between which each hand points, or the figure to which it points, beginning at the left-hand dial; then add two ciphers to the right of the three figures, and the number so obtained will be the

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amount of gas in cubic feet which the meter has measured. Thus, the pointers in the diagram indicate that 14,200 cu. ft. of gas have passed through the meter.

The dial marked *two feet* may be used to ascertain the quantity of gas consumed per hour by a burner, by noting the time required for the pointer to make a revolution. Thus, the hand will make 2½ revolutions per hour if 5 cu. ft. pass through the meter in that time. This dial may also be used in testing for leaks.

Pressure Regulators.—The objects sought in the use of pressure regulators or governors are economy in the consumption of gas, steadiness of the lights, and most effective operation of the burners. It is of great importance that both volume and pressure at the burners should be closely regulated. The amount of gas wasted by overpressure is much greater than is generally believed. A good new lava-tip burner consuming 5 cu. ft. per hr. at .5 in. pressure, will consume about .5 of a cu. ft. more for each increase of .1 in. in the pressure. Thus, an overpressure of .1 in. will increase the gas bill about 10 per cent. The variation, in even the best-regulated systems, is usually much greater than $\frac{1}{10}$ in., and is frequently $\frac{1}{8}$ or more.

The two systems of regulation in use are the *pressure* and the *volumetric* regulation. In the first system, a governor is attached to the service pipe at the meter, and the house distributing pipes are maintained at constant pressure; in the second system, each burner is supplied with a governor, the pressure in the pipes not being controlled.

The proper place for a pressure regulator, if used, is between the meter and the main.

The pressure required at the burners, to secure the best results, varies greatly in different forms of apparatus. The following are the pressures generally used:

Argand burners	.2 in. of water.
Common batswing burners	.5 in. of water.
Wellsbach incandescent burners	.5 in. or more.
Wenham and Lebrun lamps	.5 to 1 in. or more.
Atmospheric burners	1.0 in. or more.

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GAS-FITTING.

ILLUMINATION REQUIRED.

The number of gaslights required to properly illuminate a room depends on its size, condition of wall surfaces, etc. The reflection from the walls in small rooms is proportionately greater than in large ones, and hence a smaller number of burners is required in proportion to the floor space. A 5′ (cu. ft. per hr.) batswing burner is assumed to give a light of 16 c. p. under a pressure of .5 in. of water.

For large rooms, such as a church, etc., the proper illumination will be furnished by using one burner to each 40 sq. ft. of floor. If there are balconies, etc., extra lights must be provided according to the same rule. For smaller rooms, such as are found in ordinary dwellings, the proportion may be one light to about 80 sq. ft. of floor. The amount of light required is, therefore, from .4 to .2 c. p. per sq. ft., according to the size of the room.

If incandescent gaslights, such as the Wellsbach, are used, the number of lights may be much less, as these lights furnish from 50 to 60 c. p. on a consumption of about 3 cu. ft. of gas per hr., at a pressure of .5 in.

CANDLEPOWER OF 4-FT. UNION JET BURNER AT DIFFERENT PRESSURES.

Gas Pressure. Inches of Water Column.	Gas Consumed per Hour. Cubic Feet.	Light Emitted per Cubic Foot. Candlepower.	Candlepower of Flame.
.5	3.90	3.00	11.70
1.0	5.60	2.40	13.40
1.5	7.00	1.90	13.30
2.0	8.45	1.50	12.67
2.5	9.60	1.35	12.96
3.0	10.50	1.11	11.65

NOTE.—The best pressure for ordinary illuminating gas is 5 in. of water.

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The amount of illuminating gas consumed in an ordinary burner depends on the pressure of the gas. An increased consumption of gas does not correspondingly increase the supply of light, as will be seen by the preceding table.

SIZE OF PIPES.

Each pipe must have enough capacity to supply all its burners when they are in full operation. Allowance must also be made for all heating and cooking apparatus likely to be required. The quantity required for lighting may be reckoned as 5 cu. ft. per hr. for each burner, unless otherwise given. The actual quantity required by improved burners, however, differs so much that it is impracticable to compute the volume required by merely noting the number of burners and multiplying this number by 5.

CAPACITY OF GAS PIPES.

Diameter of Pipe. Inches.	Maximum Length. Feet.	Capacity per Hour.	
		Coal Gas. Cubic Feet.	Gasoline Gas. Cubic Feet.
¼	6	10	
⅜	20	15	10
½	30	30	20
¾	50	100	75
1	70	175	125
1¼	100	300	200
1½	150	500	350
2	200	1,000	700
2½	300	1,500	1,100
3	450	2,250	1,500
4	600	3,750	2,500

Service pipes should never be less than ¾ in. because of liability to chokage, and, if of iron, it is advisable to make the diameter at least 1 in. For small cook stoves, the supply pipe should be at least ¾ in., and for larger stoves, 1 to 1½ in.

Having ascertained the probable maximum quantity required in cubic feet per hour, the diameter of the pipe can

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be found from the table "Capacity of Gas Pipes." If the length of the proposed pipe exceeds the maximum length given, the next larger size pipe should be chosen. If the pressure exceeds 2 in., the principal pipes may be reduced one size. If the pressure is less than 1 in., all pipes must be increased one size, and with very long pipes, the diameter will require to be increased still more. When gasoline gas is used, no distributing pipe should be less than ¾ in.

In this table, the pressure is assumed to be about 2 in. of water. The quantities stated are those which the pipes will deliver at the burners without objectionable fall of pressure.

INSTALLATION AND TESTING.

The pipes used for the distribution of gas in buildings are standard plain wrought-iron or steel pipe.

If the location of the pipes is not shown by the architect, then the gas-fitter must use his own judgment in determining their position. He should be governed by the following considerations:

1. The pipes should run to the fixtures in the most direct manner practicable.

2. The pipes must be graded to secure proper drainage without excessive cutting of floorbeams, or otherwise damaging the building.

3. Pipes that run crosswise of floorbeams should be laid not more than 1 ft. from the wall, to avoid serious injury to the floor.

4. Fixtures should be supplied by risers rather than by drop pipes, as far as practicable.

5. All pipes should be located where they can be got at for repairs, with the least possible damage to the floors or walls.

6. The fittings should be malleable-iron galvanized, beaded fittings being preferable to plain ones. Plain black-iron fittings should never be used on important work.

The fittings commonly used in gas-fitting are shown in the accompanying illustration.

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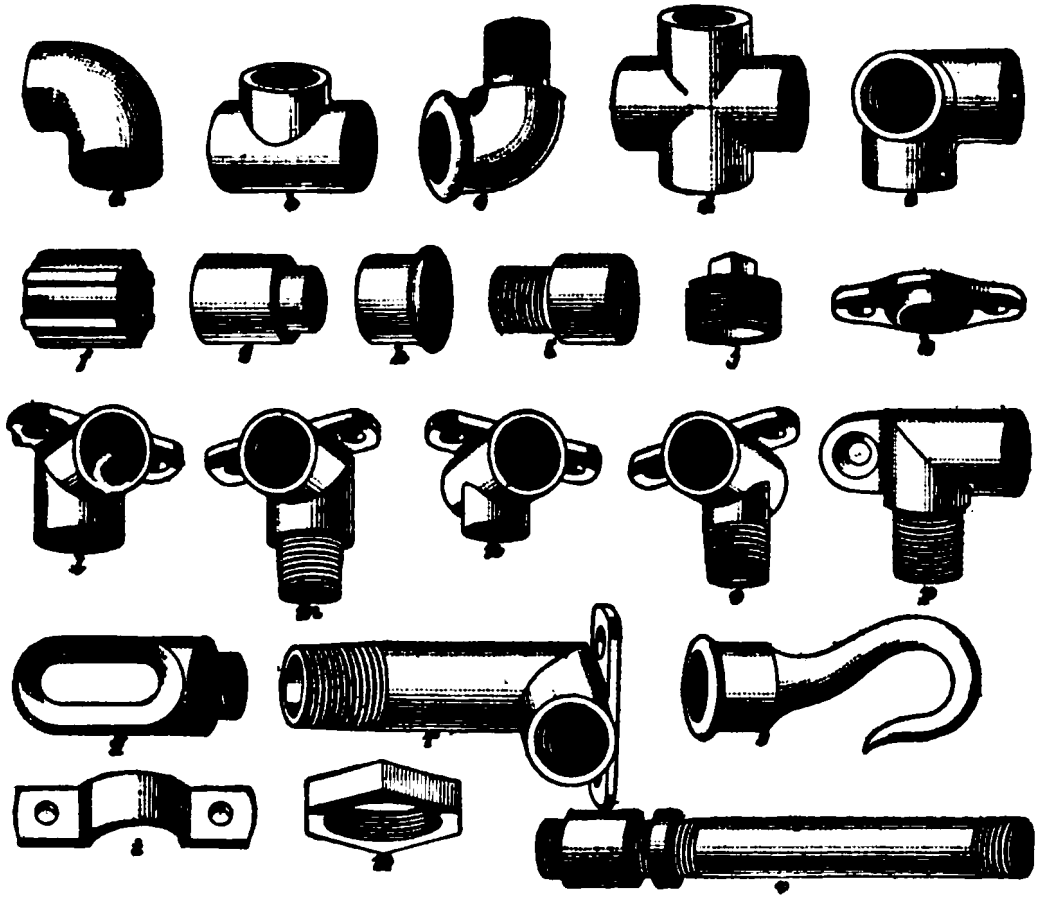
Their names are: *a*, quarter elbow; *b*, tee; *c*, street elbow; *d*, cross; *e*, elbow with side outlet; *f*, right-and-left coupling; *g*, reducing coupling; *h*, cap; *i*, male and female extension piece; *j*, plug; *k*, waste nut; *l*, drop elbow with female thread; *m*, drop elbow with male thread; *n*, drop tee with female thread; *o*, drop tee with male thread; *p*, drop elbow with male thread, left flange; *q*, male chandelier loop; *r*, drop elbow with long outlet piece; *s*, chandelier hook, female;



t, pipe strap; *u*, locknut; *v*, long screw. The flanged fittings can be had either right or left, and also with male or female threads.

The threads on a $\frac{1}{8}''$ gas pipe will sustain a weight of about 5,000 lb.; on a $\frac{1}{4}''$ pipe, about 7,000 lb.; and on a $\frac{3}{4}''$ pipe about 9,000 lb. Hence, gas pipes securely anchored will easily support any reasonable weight of chandeliers attached to them.

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PIPING GAS RANGES.

The size of single lines of pipe run from or near a gas meter to a gas stove or gas range should be in accordance with the following table:

SIZE OF PIPE FOR GAS STOVES AND RANGES.

Average Inside Size of Oven. Inches.	Maximum Distance of Stove From Meter. Feet.	Nominal Size of Service Pipe Required.
11 × 11 × 14	30	¾
11 × 11 × 14	60	¾
14 × 14 × 24	30	¾
14 × 14 × 24	60	¾
16 × 16 × 24	30	¾
16 × 16 × 24	60	1
19 × 19 × 24	30	1
19 × 19 × 24	60	1¼

TESTING.

As soon as all the pipes are in place and are properly secured, the system should be tested to find if it is gas-tight. Air should be forced in the system until the gauge indicates 15 or 20 in. of mercury, or 7 to 10 lb. per sq. in., the pressure being continued for about 1 hr.; if the gauge shows a falling off in pressure of more than ¼ in. of mercury, or ⅛ lb. per sq. in., the system cannot be passed as perfect. The mercury-column differential proving gauge is well adapted for testing gas pipes, etc. that are to be made air-tight; common spring gauges are unreliable.

The extent of a leak may be judged by the rapidity of the fall in pressure, but its location must be found by the sense of smell. For this purpose a small quantity of ether should be introduced into the pipes. The vapor of the ether will diffuse throughout the system and escape from the leak, where it will be detected by its odor. The gauge should be provided with an ether cup especially for testing purposes.

In the case of large buildings, it is advisable to test the

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piping in sections, say one floor at a time, because then it is much easier to locate leaks. After each section is tested they may be connected, and then subjected to a final test.

The pipes should not be covered until the tests are completed. The owner, architect, or inspector should witness the tests.

ACETYLENE GAS-FITTING.

The Piping.—The chief differences between ordinary gas-fitting and acetylene gas-fitting are: (*a*) special burners or tips, (*b*) a gas machine or generator, and (*c*) smaller distributing pipes. Otherwise, there is no substantial difference between them. Buildings piped for coal gas can ordinarily be lighted by acetylene by disconnecting the service pipe from the street and attaching it to a gas machine, and by substituting acetylene tips for the common gas tips.

If a building is piped for acetylene gas only, the sizes of the piping may be about as follows:

CAPACITY OF ACETYLENE GAS PIPES.

Nominal Diameter of Pipe. Inches.	Maximum Length of Pipe. Feet.	Number of ⅛′ Burners to be Supplied.
¼	20	4
⅜	40	7
½	60	15
¾	100	50
1	150	80
1¼	250	150

Underwriters' Requirements.—The requirements of the New York Board of Fire Underwriters for the installation of acetylene-gas generators are as follows:

1. Plans and specifications in detail of acetylene-gas generators must be submitted to this Board for approval, and a copy of the same placed on file in this office. If the plans are approved, a special examination of the generating apparatus

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will be made (at the expense of the applicant), and if it is found to be in compliance with the following requirements, a certificate of approval will be granted:

2. The generating apparatus must be located in an outside, fireproof, and well-ventilated building, where it will not be an exposure to any adjoining property. The buildings in which generators having a capacity of more than 25 lb. and not exceeding 100 lb. of calcium carbide are placed, shall not be located within 10 ft. of any other building; and the buildings in which generators having a larger capacity than 100 lb. and not exceeding 500 lb. of calcium carbide are placed, shall be restricted to a distance of not less than 25 ft. from any other building, and these shall have the constant supervision of a competent person.

3. The dimensions of the generator building must be confined to the requirements of the apparatus, and the limited supply (hereinafter mentioned) of surplus calcium carbide, which must be packed in water-tight metal cans, and said buildings shall be located as follows:

For generators with capacity of more than 25 lb. and not exceeding 100 lb. of calcium carbide, and, in addition, 100 lb. of surplus carbide—not less than 10 ft. from other buildings.

For generators with a capacity of over 100 lb., and not exceeding 500 lb. of calcium carbide, and, in addition, not over 500 lb. of surplus carbide—not less than 25 ft. from other buildings.

The storage of calcium carbide on premises, other than in generator building, is absolutely prohibited.

4. In constructing the building, dryness and ventilation must be secured. To meet these requirements, the floor must be raised above the grade on which the building is located, and suitable drainage provided. Ventilation is to be obtained by air passing from the outside of building through holes at the floor and through a pipe at least 6 in. in diameter, at the roof. The said pipe must extend at least 4 ft. above the roof, and must be topped with a guard cap, and if there be any building within 10 ft. of said pipe, then the ventilating pipe must be carried 4 ft. above the roof of the higher building.

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5. The maximum pressure of gas stored in a gas holder shall be limited to 8 in. of water, and both the generator and gas holder shall have water safety seals (not to exceed the same limit) in connection with escape pipes of not less than 1¼ in. in diameter. The escape pipes must be connected above the roof with the ventilating pipe of the building in which the generator is located.

6. A generator in which the gas is both generated and stored (the maximum pressure of which shall not exceed 5 lb. per sq. in.) and having no water seal, shall be tested to withstand a hydraulic pressure of 20 lb. per sq. in. The generator shall have a pressure gauge, also a safety valve (not less than 1¼ in. in diameter) adjusted to release the pressure of the gas should it rise above the prescribed maximum limit. An escape pipe must be affixed to the safety valve, and connected above the roof to the ventilating pipe of the building in which the generator is located. A certificate attesting the hydraulic test is to be placed on file in this office.

7. The pressure of the gas shall be regulated at the generator or gas holder, so that it will not exceed 4 in. of water on the pipes inside of the building to be lighted. A mercurial seal, set to that pressure, must be attached to the supply pipe at the generating building. A stop-valve shall be placed on the supply pipe at the place where it enters the inside of the building to be lighted

8. All generators and gas holders shall be connected by at least 1¼″ escape pipes and stop-valves with the ventilating pipe at the roof of the building, through which the gas can be conveyed and discharged with safety on the outside of the building.

9. Generators must be constructed so that they can be charged with calcium carbide at all times without allowing the gas to escape into the building.

10 Generators shall be filled with calcium carbide by daylight only and all generating apparatus must be in charge of persons who are familiar with their operation and are fully competent to manage them under all circumstances.

11. No artificial light, except a wire-guarded incandescent

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electric light, may be used inside of the building in which the gas is generated, and no heat except low-pressure steam.

12. All acetylene-gas generators, and all receptacles containing acetylene gas, shall be made of iron or steel throughout.

13. The residuum of the calcium carbide when removed from the generator must be deposited in a safe location outside of the building apart from any combustible material.

LIQUID ACETYLENE.

14. The storage of liquid acetylene in any building, or the use of liquid acetylene gas, is absolutely prohibited.

Requirements of a Good Generator.—The following are the points on which judgment was passed in awarding medals to the acetylene generators at the Pan-American Exposition at Buffalo, N. Y., in 1901:

1. The contact of the carbide should be with the water (in other words, the machine should be of the drop type).

2. The carbide should be fed into the water in proportion to the consumption of gas.

3. The gas pressure at the point of delivery should remain practically constant, irrespective of the number of jets burning, or of the amount of carbide, or of gas, in the generator.

4. The pressure should be equal in all parts of the machine and should not exceed that exerted by a 6″ column of water.

5. When the lights are turned out the generation of gas should cease.

6. The gas should be delivered to the burners clean, cool, and dry.

7. The heat of generation must not exceed 200° F.

8. When the generator is recharged, there should be no escape of gas.

9. If the generator is left idle for a long period, there should be no deterioration of the carbide.

10. The gas holder attached to the generator should be of ample capacity and made tight with a water seal.

11. The pressure in the service pipe should never exceed that of a 3″ column of water, and a provision must be made to blow off into the air at a pressure of 6 in.

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12. The water capacity of the generator must be at least 1 gal. of water to 1 lb. of carbide.

13. There must be a convenient method of getting rid of the slacked carbide without escape of gas.

14. The generator must be entirely automatic in its action. That is to say, after it has been charged it will need no further attention until the carbide is entirely exhausted.

15. There should be a simple method of determining the amount of unconsumed carbide in the generator at any time.

16. The generators should be so simple in operation that they can be tended by unskilled labor without danger of accident.

17. The various operations of discharging the refuse, filling with fresh water, putting in carbide, and starting the generator should be so arranged that it is impossible to do them in the wrong order.

18. The generators must be so arranged that there can be no possibility of mixing air with acetylene gas.

19. Generators must be built of substantial materials well adapted to their purpose.

20. Generators must be so constructed that an addition to the charge of carbide can be made at any time, without affecting the light.

Any generator that is built according to the preceding points may be considered excellent.

LOCATING FIXTURES.

The chief considerations that govern the location of gas fixtures are: first, that they shall light the rooms to good advantage, and second, that they shall cause no danger from fire.

A gas fixture should never be placed in a closet or other very small room, if there is any chance that the door may be closed and the light left burning. If that should happen, the temperature will rise rapidly, and there will be great danger of setting fire to any combustible material that might be in the room.

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Hot-air registers in the floor or wall should be carefully avoided in locating gas fixtures. If a light is over or near a register, it will flicker incessantly, and will be a great annoyance.

The proper height of gaslights above the floor depends somewhat on circumstances. In ordinary dwellings having a ceiling 9 ft. high or more, side lights should be placed from 5½ to 6 ft. high. Pendants may be hung from 6½ to 7 ft. from the floor. If the rooms are large and high, the lights of chandeliers may be placed at a height of 7 to 8 ft., or even more. Of course, all lights above 7 ft. high will require the assistance of a torch or step ladder to light them.

Low lights should be avoided, because they are tiresome to the eyes. If they must be used, they should be provided with opaque shades.

Chandeliers, as nearly as practicable, should be hung from the center of the ceiling. If several side lights are used in the same room, they should be placed at the same height.

Care should be taken in locating side lights, to make sure that wooden doors cannot be swung back against them, and be scorched or set on fire. Lights should not be placed where they may be blown out by strong drafts of air, or by the sudden slamming of a door. A gas burner extinguished with a full head of gas on, is very dangerous.

Side lights in hallways and vestibules or in churches and similar buildings should be placed at a height of at least 7 ft. A side light should not be placed over a set of tubs if it can be avoided. A better place is at the head of the ironing table

Swing brackets should not be used for lighting halls, stairs, vestibules, or other passageways, because of the danger from fire. The light is very liable to be swung too close to the wall, and to be overlooked until the building is set on fire. Swing brackets are always a source of danger when they are located within reach of woodwork or drapery, and therefore are not to be recommended for general use. It is preferable, in most cases, to use instead two single lights on stiff brackets, or else a bracket having two or more rigid arms with fixed lights.

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In lighting bedrooms, the fixtures should be located so that the bed, wardrobe, dressing case, mirror, etc., may be placed in desirable positions without interfering with the light. The positions of the closets should be noted, and if practicable, the light should be arranged to shine into them, so that the contents may be easily seen.

Dressing mirrors should be provided with two stiff bracket lights, one at each side. They should be placed as high as they can conveniently be reached, in order to properly illuminate the head and shoulders of the person using the mirror.

In bathrooms, the lights should be set high, so that a person will not be liable to strike them in taking off or putting on clothing. A light should not be located over a bathtub or a wash bowl, or anywhere near them, because of the liability to accident.

A kitchen or laundry should be lighted by pendants whenever practicable. If side lights must be used, they should not be placed over the sink or near enough to it to be liable to be struck or be splashed with water. The best place for a side light is usually over the pastry table.

Hallways are best lighted by a pendant; if a side light is used it should be placed where it will not interfere with the coat rack, or mirror, or other hall furniture.

A pendant in a hallway or vestibule should be set so high that the globes will not be liable to be knocked off by a person who is putting on an overcoat, etc.

Stairways should be provided with a light at the top, whether there is one at the bottom or not. A light on the newel post alone is not sufficient to properly illuminate the steps. People having defective sight are especially liable to accident on stairways, and the light should be arranged so as to avoid all shadows that might prove deceptive.

The stairway leading from the kitchen to the basement or cellar should be lighted by a burner that is located some distance from the foot of the stairs. If the light is near the foot of the stairs, it is very apt to be struck when large articles are carried past it.

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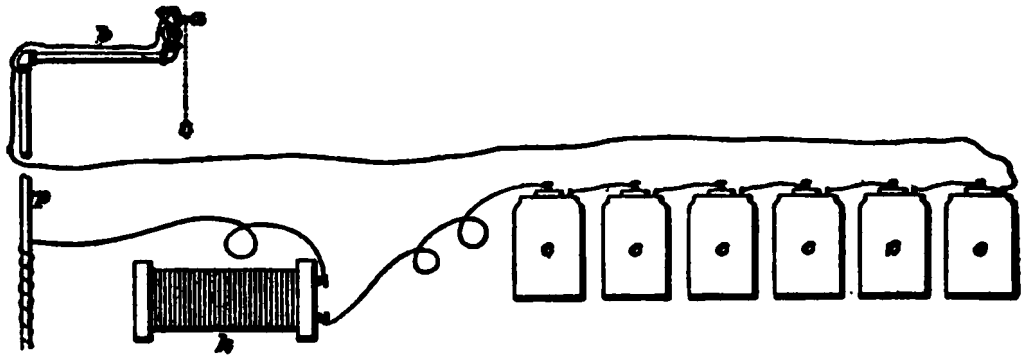
ELECTRIC GAS LIGHTING.

The arrangement of the apparatus required for electric gas lighting is shown in the accompanying illustration. A



battery of about 6 Leclanché cells *c*, *c*, etc., joined up in series, is connected to one terminal of a spark coil *k*, the other terminal of which is soldered to a gas pipe *p*. The wire from the free end of the battery is carried up through the house, and branches are run to the burners, as at *b*, wherever needed. The insulation of this wire must be very thorough, special precautions being taken when it is carried through or along the fixtures. The burners are provided with a chain *a* attached to a movable contact spring, which is drawn past the burner, producing a spark of sufficient intensity to ignite the gas if it is previously turned on.

Gas brackets usually have but a single pipe; the wire should be run on its lower side. A short helix should be made at every flexible joint to prevent breaking of the wire through frequent turning of the bracket. The wire used is No. 20 or 22, B. & S. gauge, well insulated, and colored to suit the bracket. For the house circuits, No. 14 or 16 wire should be used.

In multiple gas lighting, a fine wire is run from one burner to another of a group, leaving a small air gap at each one, and a very high-tension current is used, generated by a small frictional machine, causing a spark at each burner. The last contact in a series of burners is connected to the gas pipe.

The National Board of Fire Underwriters prohibits the use of electric gas-lighters on combination gas and electric light fixtures, if wired for electric lights and connected.

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PLUMBING.

PLUMBING MATERIALS.

DEFINITIONS AND TRADE TERMS.

A *soil stack* is a vertical line of pipe extending through the roof and receiving the discharge of one or more water closets.

A *waste stack* is a pipe extending through the roof, and receiving the discharge from any fixtures except water closets.

Waste pipes are pipes that carry the discharge from the fixtures to the soil stacks or drains.

Vent stacks are vertical lines of pipe extending up through the roof and ventilating a number of fixture traps or waste pipes on two or more floors.

Vent pipes are special pipes provided for ventilating the system of drainage or waste piping and for preventing siphonage and back pressure.

A *back-vent pipe* is a pipe connecting a trap with a vent stack or directly with the outer air.

A *trap* is a device through which liquids and particles of solid waste matter may freely pass, but which prevents the passage of air in either direction.

A *fresh-air inlet* is a pipe extending from the house side of the main drain trap to some point outdoors, where it is open to the atmosphere.

Rain leaders, or *conductors*, are pipes that conduct rain water from roofs to house drains, cisterns, or other places of discharge.

Cesspools are receptacles built underground to receive the drainage from a house system. *Leeching cesspools* are those from which the liquid sewage is allowed to soak into the surrounding earth. *Tight cesspools* are receptacles that retain all sewage matter, both liquid and solid, until the cesspool is full, when it must be pumped out or otherwise removed.

The term *house drain* is applied to that part of the main horizontal drain and its branches inside the walls of the

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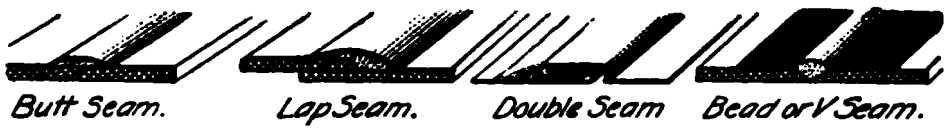

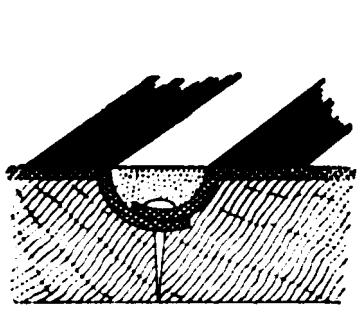

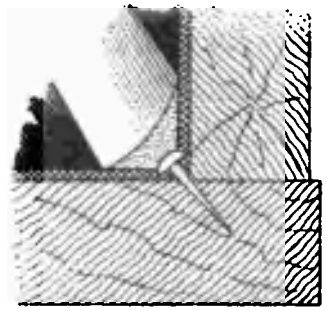

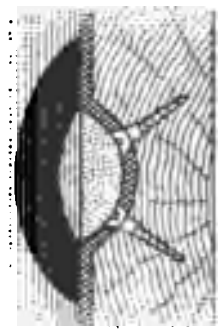

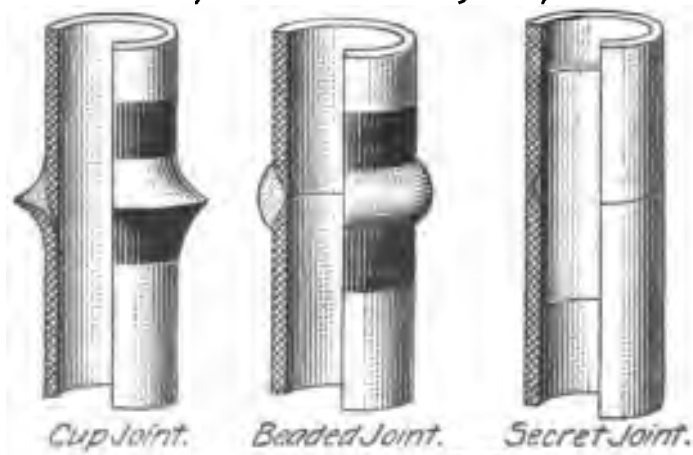

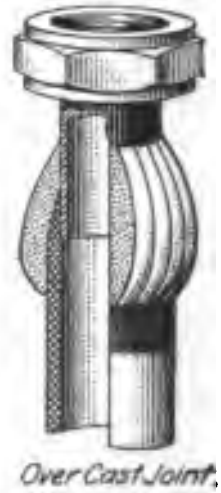

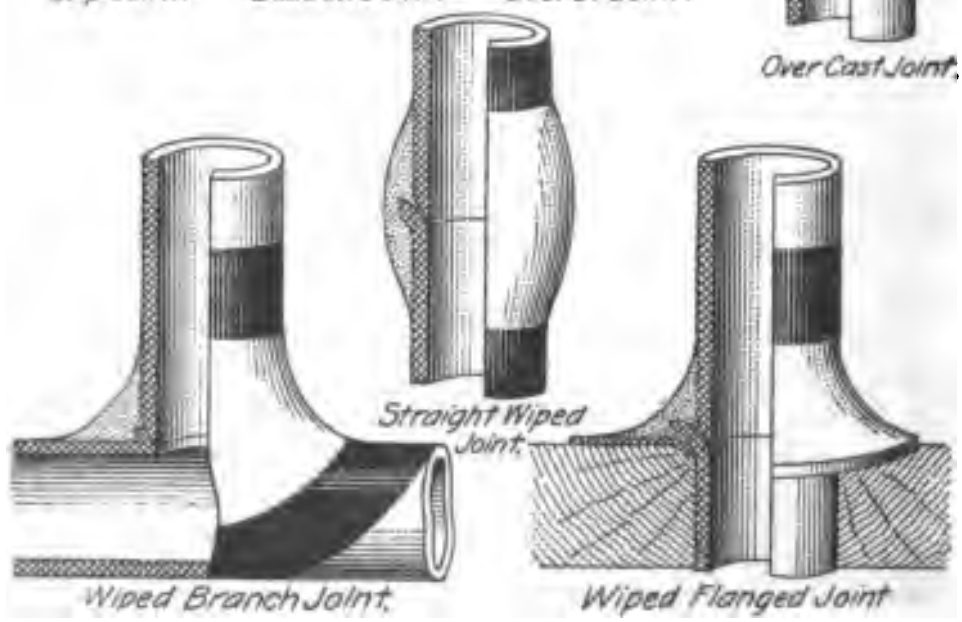

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building extending to and connecting with the house sewer.

The *house sewer* is that part of the main drain or sewer extending from the foundation wall of the building to its connection with the public sewer, private sewer, or cesspool.

A *private sewer* is a main sewer that was not constructed by or under the supervision of the city authorities; although it may be constructed in a public highway.

Flush fittings or *recessed drainage fittings* are threaded for screw connections to pipes. The bore of the fittings are flush with the inside of the pipe.

Roughing-in is the installation of the soil, waste, vent, and supply pipes from the points at which they enter a building, or through the walls or floors where the fixtures are to be set. In new buildings, this work is erected before the walls are lathed or the floors are laid.

Finishing is the setting up of the plumbing fixtures, and the connecting of them to the soil, waste, and supply pipes. This work is done after the plastering is finished and the floors are laid.

Solder joints are joints in which the parts are joined together by soft solder.

Brazed joints are those in which the parts are joined or fused together by the use of a solder made of granulated yellow brass.

Wiped joints are those in which the solder is fused on the joints and wiped to a neat smooth finish with a wiping cloth. The accompanying illustration shows different kinds of joints commonly used in plumbing.

A *flux* is a substance applied to joints to aid the solder in becoming properly fused to the metal, and in flowing into the crevices of the joints.

PIPES AND FITTINGS.

Cast-Iron Soil Pipes.—These should be uniform in thickness and homogeneous throughout. They should be tested with water pressure and then coated with asphaltum before being used.

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These pipes come in 5′ lengths and are known as *extra heavy*. The maker's name should be cast on each piece. Any pipe lighter than the following should be rejected.

WEIGHT OF CAST-IRON SOIL PIPE.

Nominal Diameter. Inches.	Weight per Foot. Pounds.	Nominal Diameter. Inches.	Weight per Foot. Pounds.
2	5½	7	27
3	9½	8	33½
4	13	10	45
5	17.	12	54
6	20		

Cast-iron soil-pipe *fittings* should correspond with the grade of pipes used. They should have easy curves. No sharp 90° bends or T branches should be used; only obtuse angle fittings. Fittings are made as staple goods at the following angles: 90°, 45°, 22½°, 11¼°, and are known as quarter, eighth, sixteenth, and thirty-second fittings, respectively.

The various forms of cast-iron soil-pipe fittings that are on the market, and their trade names, are given in Figs. 1 and 2.

Cast-iron soil-pipe *joints* are made with picked oakum and molten lead calked solidly home in the sockets; 12 oz. of soft pig lead must be used in each joint for each inch in diameter of the pipe.

To cut a cast-iron soil pipe, it should be laid on a mound of earth, if practicable, rather than on a stone or a block of wood. A groove is then cut around the pipe either with a cape chisel or a thin and sharp cold chisel. The chisel should not be held square with the pipe, but should be inclined toward the end of the pipe, the object being to chip a V groove around the pipe. After every blow of the hammer the chisel should be shifted, or the pipe should be turned. When the groove has been cut deep enough, the pipe can be broken off clean and square by a sharp blow on one end.

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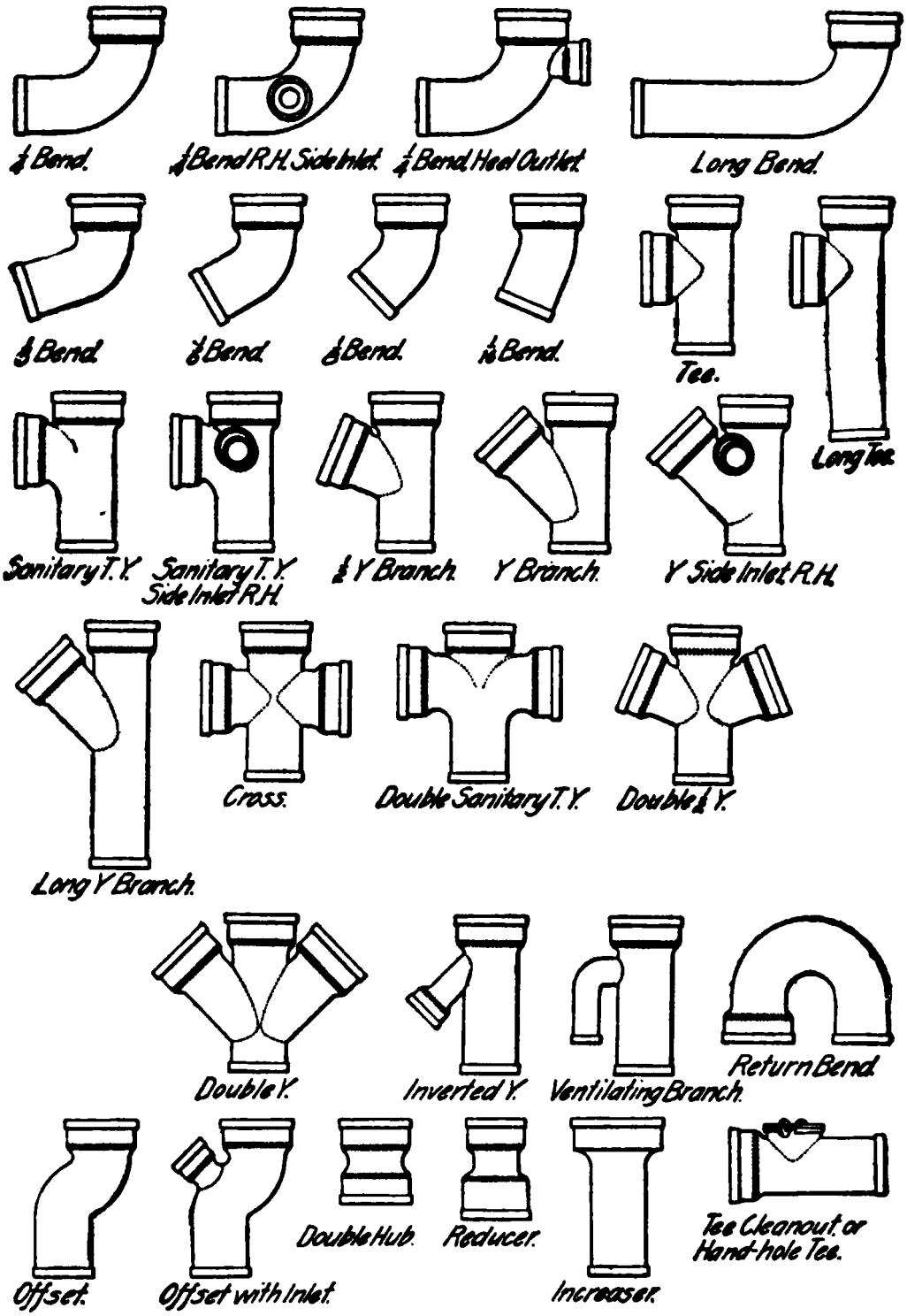

FIG. 1.

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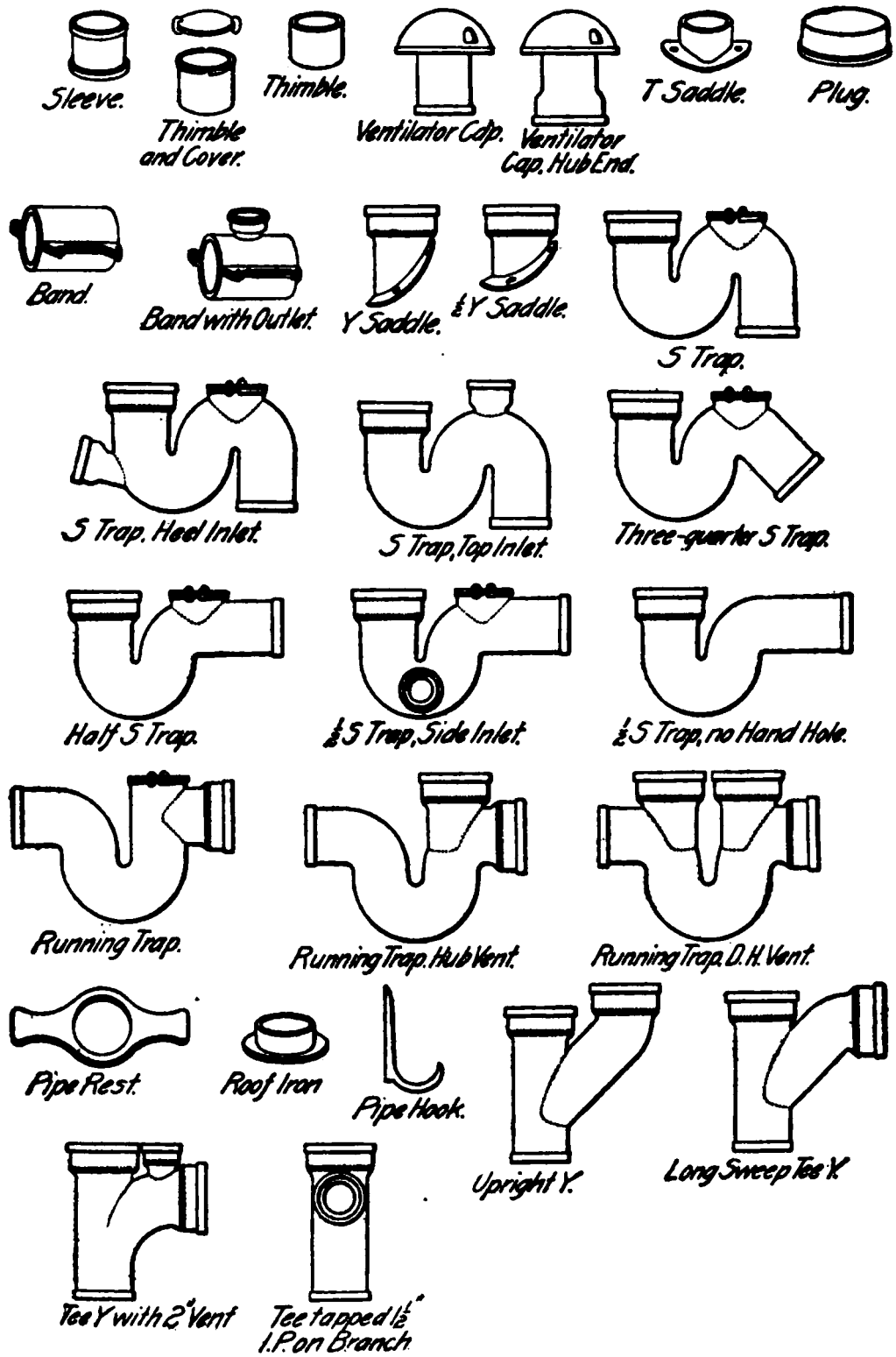

FIG. 2.

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Wrought-Iron and Steel Pipes.—When used for drainage purposes these should be stamped with the maker's name. They should be galvanized and conform to the following table:

WEIGHT OF WROUGHT-IRON OR STEEL DRAINAGE PIPE.

Nominal Diameter. Inches.	Thickness of Metal. Inches.	Weight per Foot. Pounds.
1¼	.14	2.7
2	.15	3.6
2½	.20	5.7
3	.21	7.5
3½	.22	9.0
4	.23	10.7
4½	.24	12.3
5	.25	14.5
6	.28	18.8
7	.30	23.3
8	.32	28.2
9	.34	33.7
10	.36	40.1
11	.37	45.0
12	.37	49.0

Fittings for vent pipes on wrought-iron or steel pipes may be the ordinary cast or malleable steam and water fittings.

Fittings for waste or *soil pipes* must be the special, extra-heavy cast-iron, recessed and threaded, drainage fittings, with smooth interior waterway, and threads tapped so as to give a uniform grade to branches of not less than ¼ in. per ft.

All *joints* must be screwed joints made up with red lead, and the burr formed in cutting must be carefully reamed out. When the male threads are screwed up tightly, the ends should abut each other in the couplings.

Short nipples on wrought-iron or steel pipe, where the unthreaded pipe is less than 1½ in. long, should be of the thickness and weight known as *extra heavy* or *extra strong.*

Brass Soil, Waste, and Vent Pipes, and Solder Nipples.—These should be thoroughly annealed, seamless drawn, brass tubing

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of standard iron-pipe gauge. Connections on brass pipe and between brass pipe and traps of iron pipe must not be made with slip joints or couplings. Threaded connections on brass pipe should be tapered and of the same size as iron-pipe threads. The following average thicknesses and weights per lineal foot should be employed:

WEIGHT OF BRASS SOIL, WASTE, AND VENT PIPE.

Nominal Diameter. Inches.	Thickness. Inches.	Weight per Foot. Pounds.
1¼	.14	2.8
2	.15	3.8
2½	.20	6.1
3	.21	7.9
3½	.22	9.5
4	.23	11.3
4½	.24	13.1
5	.25	15.4
6	.28	20.0

Brass ferrules should be bell-shaped, extra-heavy cast brass, not less than 4 in. long and 2¼ in. in diameter. The least weight of cast-brass ferrules and solder nipples should be as follows:

WEIGHT OF BRASS FERRULES AND NIPPLES.

Ferrules.			Nipples.		
Inside Diameter.	Weight, Each.		Inside Diameter.	Weight, Each.	
In.	Lb.	Oz.	In.	Lb.	Oz.
			1¼	0	8
			2	0	14
2¼	1	0	2½	1	6
3½	1	12	3	2	0
4½	2	8	4	3	8

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Particular care should be taken to inspect all cast-brass ferrules before calking them in place, as they are very liable to have sand holes in them, which will cause annoyance in testing the roughing when finished.

Recess Drainage Fittings.—These fittings, sometimes called *flush fittings*, are used in connection with wrought-iron pipe in the installation of drainage systems. The *Durham system* is constructed of wrought-iron pipes and flush fittings. The essential feature of these fittings is that the bore of the fitting is the same as that of the pipes with which they are used. The fittings can be had plain, dipped in asphaltum, or galvanized, the latter being commonly used in conjunction with galvanized pipes If ordinary pipe fittings are used for drainage purposes, the pipes will soon become choked, because the ends catch and hold solid matter.

A number of the fittings commonly used by plumbers are shown in Fig. 3. Commencing at the top and reading to the right their names are: **Y** branch; **T Y** branch; 90° long bend; 45° bend; double **T Y** branch; **T Y** with side outlet; short 90° bend; 22½° bend; **T** branch; 60° bend; 11¼° bend; running trap with two clean-outs; one half **S** trap with vent outlet.

Lead Pipes.—The weight of lead pipe should conform to the following table:

WEIGHT OF LEAD SOIL, WASTE, AND VENT PIPE.

Nominal Diameter. Inches.	Weight per Foot. Pounds.	Nominal Diameter. Inches.	Weight per Foot. Pounds.
1¼	2½	3	6
1½	3	4	8
2	4	4½	8

This grade is known in commerce as **D**. All lead traps and bends should be of the same weight and thickness as their corresponding pipe branches.

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Miscellaneous Materials.—*Oakum* is a hemp fiber moistened with pine tar, and capable of being packed very tightly into crevices. It is used extensively for calking joints in soil pipe.

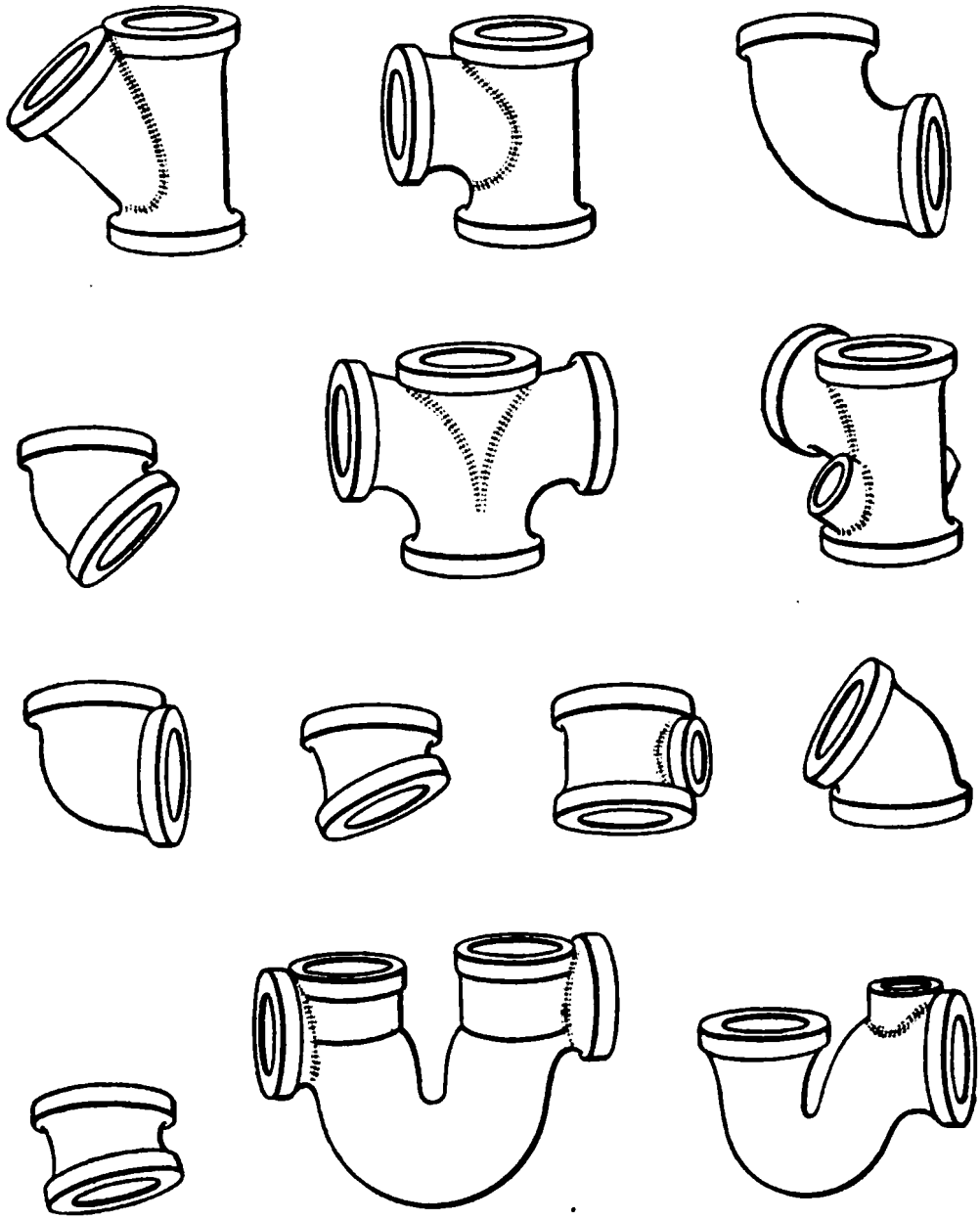

FIG. 3.

Asphaltum is a native mineral pitch or bitumen used extensively for coating pipes. It is black or dark brown in color, and fractured surfaces have a high luster. The specific

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gravity is about 1.10. It melts readily and burns without residue, being completely soluble in petroleum or turpentine. Pipes that are to be coated should be heated to the melting point of the asphaltum before being dipped.

Plaster of Paris is used in plumbing chiefly for setting marble work. It should be mixed with water in small quantities to the consistency of thick cream and should be used as quickly as possible, for it sets rapidly. It should never be disturbed when setting nor used after it has begun to set.

Portland cement is used by plumbers chiefly for joining earthenware pipes. For that purpose it is best when mixed with an equal quantity of clean, sharp sand. Good Portland cement will set under water.

Rosendale cement is not suitable for joining earthenware pipes, but may be used for building manholes and similar masonry. It is similar to Portland cement, but does not possess the same degree of strength or the property of setting under water.

Glaziers' putty is a mixture of about 7 parts, by weight, of whiting to 3 parts of boiled linseed oil. When mixed with white or red lead it makes a suitable cement for bedding down water closets.

Red lead is an oxide of lead and is sold in powdered form. It is used in plumbing chiefly as a paste for pipe threads, and to mix with putty for bedding purposes. Red lead is prepared for use by being mixed to the consistency of batter with boiled linseed oil; only a small quantity should be mixed at a time, as it sets in a short time and becomes very hard.

White lead is a carbonate of lead ground to a fine paste in boiled linseed oil. It is the basis of nearly all good house paints, and is used by plumbers for the same purpose as red lead.

INSPECTION OF MATERIALS.

To install a creditable plumbing job it is necessary to use good material only. All materials should be inspected when received and before being accepted.

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Black sheet iron should be examined for flaws or holes on its surface, for equality of thickness, and as to its liability to crack if bent sharply either with or across the grain.

Galvanized sheet iron should be examined for the same defects as black sheet iron. The zinc coating may be tested by bending the iron at a temperature of about 60° or 70° F. If the zinc adheres properly to the iron it will not scale or peel off.

Sheet copper, *sheet lead*, and *sheet zinc* are generally accepted as they are placed on the market.

Lead pipe should be soft and pliable. Examine for kinks, bruises, and punctures caused by rough handling during shipment; otherwise, it is placed on the market in good condition and requires no further inspection.

Tin-lined lead pipe should have its interior surface examined, if possible, to see if it really is tin-lined. Shave off the end of the pipe square and clean, and ascertain the thickness of the tin lining by breathing on the freshly cut end. The breath will discolor the surface of the lead with a thin blue coating, and the tin will remain bright. The thickness of the tin lining will thus become visible.

Block-tin pipe, like lead pipe, is generally accepted as reliable in the form placed on the market. Pure block tin may be detected by a peculiar crackling noise it makes when being bent at ordinary temperatures.

Seamless brass tubing should have an equal thickness all around, and should be slightly annealed to prevent its being too brittle for working. The very hard varieties are liable to split, not only while in the pipe vise, but after they have been in service for some time. Tinned semiannealed pipe is strictly reliable.

In *brazed brass* and *copper tubing* the brazed seams should be examined carefully. The seams should be uniformly loaded with hard solder and thoroughly sweated.

Galvanized-iron pipe is sometimes partly choked by the zinc used to galvanize it clogging in lumps. This may be detected by rolling a marble a size smaller than the pipe through its entire length, or, if possible, by looking through it.

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The quality of the galvanizing may be observed by bending the pipe at an ordinary temperature, to an easy bend. If the galvanizing is good it will remain intact. Galvanized-iron pipes are liable to be quite brittle, but this brittleness does not seem to affect the durability of the pipe. The ductility of galvanized-iron pipes is less than that of black iron pipes, and sometimes is so low that if the pipe is bent successfully it cannot be bent back without breaking.

In *black wrought-iron pipe* the welded seam that runs the whole length of the pipe should be scarcely visible, and the pipe should have a smooth external and internal surface. The pipes should be straight and the threads cut clean.

Mild steel pipe is the same in dimensions as wrought-iron pipe, but is softer, more easy to cut and thread, and is more durable.

Wooden pipes should be examined chiefly for knots, splits, and cross-grained wood, as these weaken the tube.

Cast-iron soil pipes should be examined for sand holes, flaws, and splits in the pipe. A fracture can be detected by tapping the pipe with a chisel or small hammer. If the pipe is sound, it will ring clearly when struck; but if cracked, it will give a dull, harsh sound. Sometimes the core will shift when the pipe is being cast, particularly if the pipe is cast horizontally, in which case the core is liable to rise in the middle. This will cause the metal to be thicker on one side than the other of the pipe. Irregularities in thickness can be detected by irregularities of the sound when rapped with a hammer at various points.

Flaws, or places where the metal has not flowed together and become properly united, can be detected by sounding the pipe with a hammer, or by its appearance, if the flaws are external.

Earthen drain pipes are liable to warp and twist in firing. They should be examined for an equal caliber, smooth-glazed internal and external surface, and particularly for cracks around the back of the socket and irregularities within the socket. Pipes having broken or crooked sockets should be rejected.

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Fittings for wrought-iron and brass pipe should be inspected for sand holes and flaws; the screw threads should be deep and full. Fittings for cast-iron drain pipes should be examined for sand holes, splits, and other flaws, and for lumps and other obstructions to the free flow of sewage.

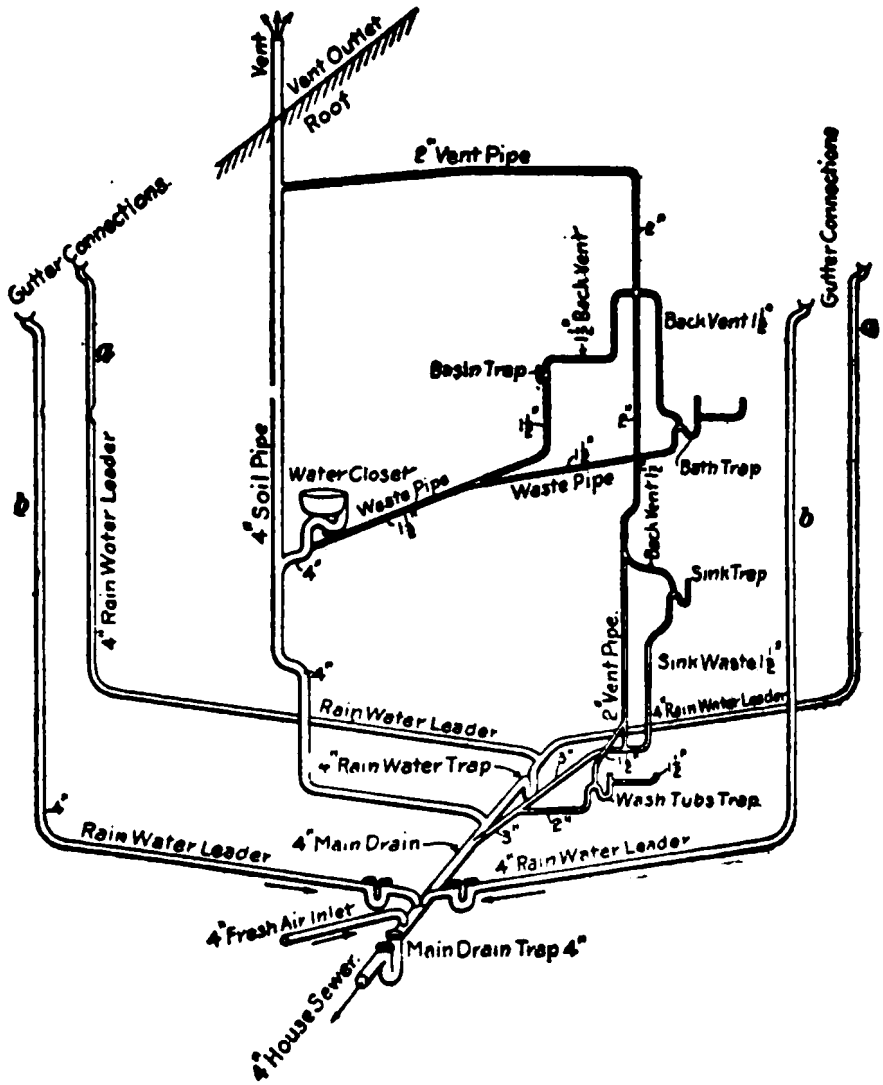

FIG. 1.

Fittings for earthen pipe should be examined for irregularities in cross-section, or caliber, for cracks, protruding pieces of salt glaze, abrupt turns, etc. The sockets should be examined to see that they are round and of proper depth. All defective fittings should be rejected.

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HOUSE-DRAINAGE SYSTEM.

GENERAL ARRANGEMENT.

The drainage system in a building usually consists of a main house drain, stacks of soil, waste, and vent pipes, short branch connections, rain leaders, and yard and area drains. The vent pipes are a necessary accompaniment. The various parts are shown and named in the isometric illustration, Fig. 1.

Main-drain and rain-water traps in a cellar may advantageously be arranged in a brick manhole, as shown in Fig. 2.

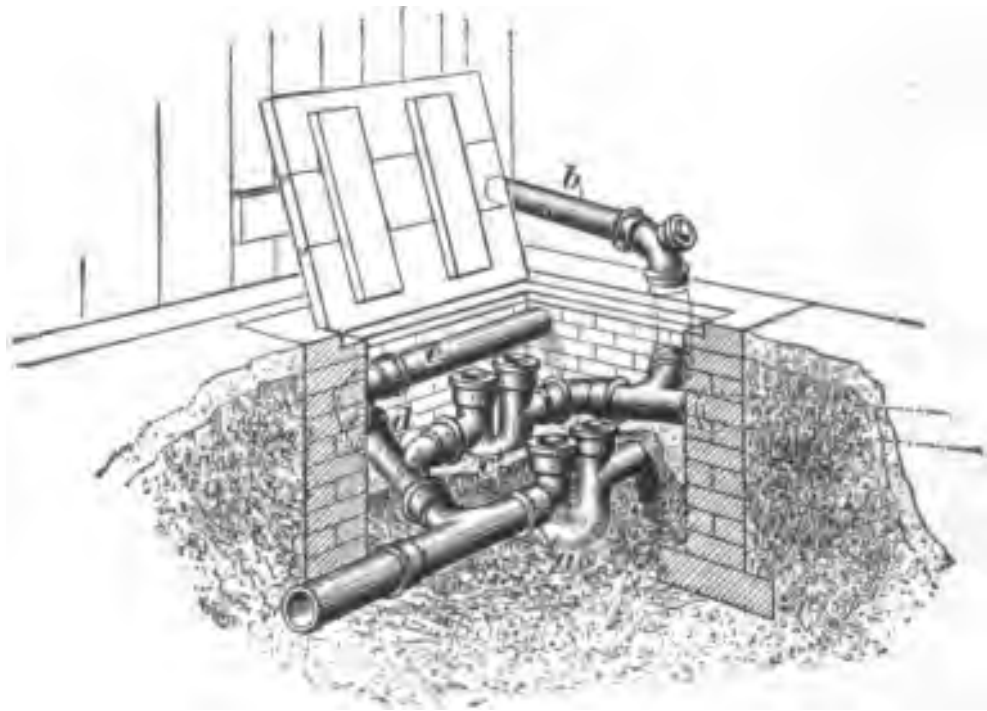

FIG. 2.

The main-drain trap *a* is provided with two brass screw-cap clean-outs flush with the floor of the manhole. The rain-water leaders discharge through the pipe *b* into a rain-water trap *c*, which is set a little higher than the main-drain trap, so that the rain water may discharge into the sanitary T fitting *d* on the fresh-air inlet pipe *e*. Each underground trap is thus accessible and can easily be cleaned at any time.

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DRAINAGE SYSTEM DETAILS.

Sizes of Pipes.—House sewer and drain pipes must be at least 4 in. in diameter where water closets discharge into them. Where rain water discharges into them, the house sewer and the house drain up to the leader connections should be in accordance with the table "Size of Pipe for Drainage." The various soil, waste, and vent pipes should correspond in size to that given in the table "Least Sizes of Soil, Waste, and Vent Pipe."

SIZE OF PIPE FOR DRAINAGE.

Diameter. Inches.	Drainage Area. Square Feet.	
	Fall ¼ In. per Ft.	Fall ⅛ In. per Ft.
6	5,000	7,500
7	6,900	10,300
8	9,100	13,600
9	11,600	17,400

For fixtures other than water closets and slop sinks and for more than 8 stories, vent pipes may be 1 in. smaller than above stated.

All vent pipes that pass through the roof should be increased one size through and above the roof to allow for ice accumulations inside. In no case should any of these pipes be less than 4 in. in diameter, except in mild climates. Care should be taken to prevent the use of the old-fashioned, cast-iron vent caps. If the open end must be protected, wire baskets may be used.

The fresh-air inlet should be of the same size as the drain, up to 4 in.; for 5″ and 6″ drains, it should not be less than 4 in. in diameter; for 7″ and 8″ drains, not less than 6 in. in diameter; and for larger drains, not less than 8 in. in diameter. The fresh-air inlet orifice should have an area equal to that of the pipe.

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LEAST SIZES OF SOIL, WASTE, AND VENT PIPE.

Name of Pipe.	Diameter. Inches.
Main and branch soil pipes	4
Main waste pipe	2
Branch waste pipes for kitchen sinks	2
Soil pipe for water closets on 5 or more floors	5
Waste pipe for kitchen sinks on 5 or more floors	3
Bath or sink waste pipe	1½–2
Basin or urinal waste pipe	1¼–1½
Pantry-sink waste pipe	1½
Safe waste pipe	1 –1½
Water-closet trap	3¼–4
Wash tubs, 1½″ waste pipe and 2″ trap for set of 2 tubs	1½–2
Waste pipe for a set of 3 or 4 tubs	2
Main vents and long branches	2
Water-closet vents on 3 or more floors	3
Vent pipe for other fixtures on less than 7 floors	2
Vent pipe for fixtures on 8 stories or less	3
Vent pipe for 9 stories and less than 16	4
Vent pipe for 16 stories and less than 21	5
Vent pipe for 21 stories and over	6
Branch vents for traps larger than 2 in.	2
Branch vents for traps 2 in. or less	1½

Fall for Drain and Waste Pipes.—The fall of a drainage system should be so arranged that the velocity of the flow obtained will be not less than about 275 ft. per min. This velocity can be closely approximated by pitching the pipes as follows:

GRADES FOR DRAIN PIPES.

Diameter. Inches.	Fall.	Diameter. Inches.	Fall.
2	1′ fall in 20′ run	7	1′ fall in 70′ run
3	1′ fall in 30′ run	8	1′ fall in 80′ run
4	1′ fall in 40′ run	9	1′ fall in 90′ run
5	1′ fall in 50′ run	10	1′ fall in 100′ run
6	1′ fall in 60′ run		

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Sizes of Stacks.—In proportioning the sizes of stacks for large office buildings, hotels, etc., the table "Sizes of Soil Stacks" has been found in practice to give good results for the corresponding number of fixtures.

SIZES OF SOIL STACKS.

Diameter of Stack. Inches.	Number of Fixtures.
4	1 to 15
5	16 to 30
6	31 to 50
7	51 to 80
8	81 to 120
9	121 to 200
10	201 to 300

The tabulated sizes of vent stacks have been found to give good results with the accompanying sizes of soil or waste pipes:

SIZES OF VENT STACKS.

Diameter of Soil or Waste Stack. Inches.	Diameter of Accompanying Vent Stack. Inches.
2	2
3	2
4	2½
5	3
6	3
7	4
8	4
9	4½
10	5
11	5
12	6

Traps and Back-Vents.—Traps for fixtures should correspond in size to the waste pipes with which they connect, and should

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be set true with respect to their water seals. The table "Sizes of Traps and Back-Vents" gives the sizes of traps for all kinds of plumbing fixtures and the sizes of corresponding vent pipes, called *back-vents.*

SIZES OF TRAPS AND BACK-VENTS.

Kinds of Fixtures.	Diameter of Trap. Inches.	Diameter of Vent Pipes. Inches.
Water closets	3–4	2
Slop sinks	2–3	1½–2
Urinals	1½–2	1½
Wash basins	1½	1½
Laundry tubs	1½–2	1½
Kitchen sinks	2	1½
Bathtubs	1½	1½
Shower baths	1½–2	1½
Seat baths	1½	1½
Foot-baths	1½	1½
Bidets	1½	1½

Under ordinary atmospheric conditions, the water forming the seal of a ventilated siphon trap will be lost by evaporation within 30 da. when the fixture is not used.

Height of Fixtures.—The most suitable heights above the floor at which to set plumbing fixtures are as follows: Slop sinks, 28 in.; urinals, 26 in.; wash basins, 30 in.; laundry tubs, 32 in.; kitchen sinks, 30 in.; pantry sinks, 30 in.

TESTING PLUMBING.

Kinds of Tests.—Drainage systems in all well-regulated cities are inspected and tested twice before being passed by the authorities as perfectly sanitary. These tests are: (1) A test of the *roughing in*, which consists of the soil, waste, vent lines, and the fixture branches, before any pipes are concealed. (2) A test of the entire system when the fixtures are all set, the traps sealed with water, and the work otherwise complete.

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The Water Test.—The roughing test is accomplished by closing all branches and filling the system with water (if the weather permits), allowing the water to stand in the pipes for a certain time, say, about 10 min., depending on the inspector's judgment. Any leaks can be detected by water flowing from them. In applying this test, particular care must be taken to use in the lower openings plugs that cannot be blown out by the heavy pressures that occur at these points.

The Air Test.—Should the weather be too cold for the water test, the compressed-air test is applied. In this case air is pumped into the system until the pressure is 10 lb., by the gauge, when a valve between the pump and the system is closed. The presence of leaks is made manifest by the gauge indicating a decreasing pressure as the test continues. The leaks may be located by the bubbles formed when a soap-and-water solution is applied to the joints with a brush.

The Smoke Test.—The final test is the more important one. The chief objects are to positively ascertain: (*a*), if the system, when completed, is gas-tight; (*b*) if the traps have perfect seals; (*c*) if every part of the system is trapped that should be trapped; (*d*) if any back-vent pipes are run into hollow partitions, attics, or chimneys. The final test commonly employed by leading sanitary authorities is known as the *smoke test.*

The principles involved in making a smoke test are shown by the accompanying illustration. The smoke machine is connected by a rubber hose *a* to some pipes that are joined together for the purpose of illustrating the principles, and is composed of a double-action bellows *b* and a firebox, which is shown, with fuel in it, at *c*. A water-jacket surrounds the firebox, and a cover or drum *d* is placed over the firebox so as to seal it by water in the jacket, as shown.

If the lever-handle *e* is moved sidewise, to and fro, air will be forced into the firebox through the pipe, which is provided with a three-way, lever-handle, shut-off cock *i*. The fuel in *c*, being ignited at the bottom, burns upwards, and the air supplies the oxygen necessary for a slow and incomplete

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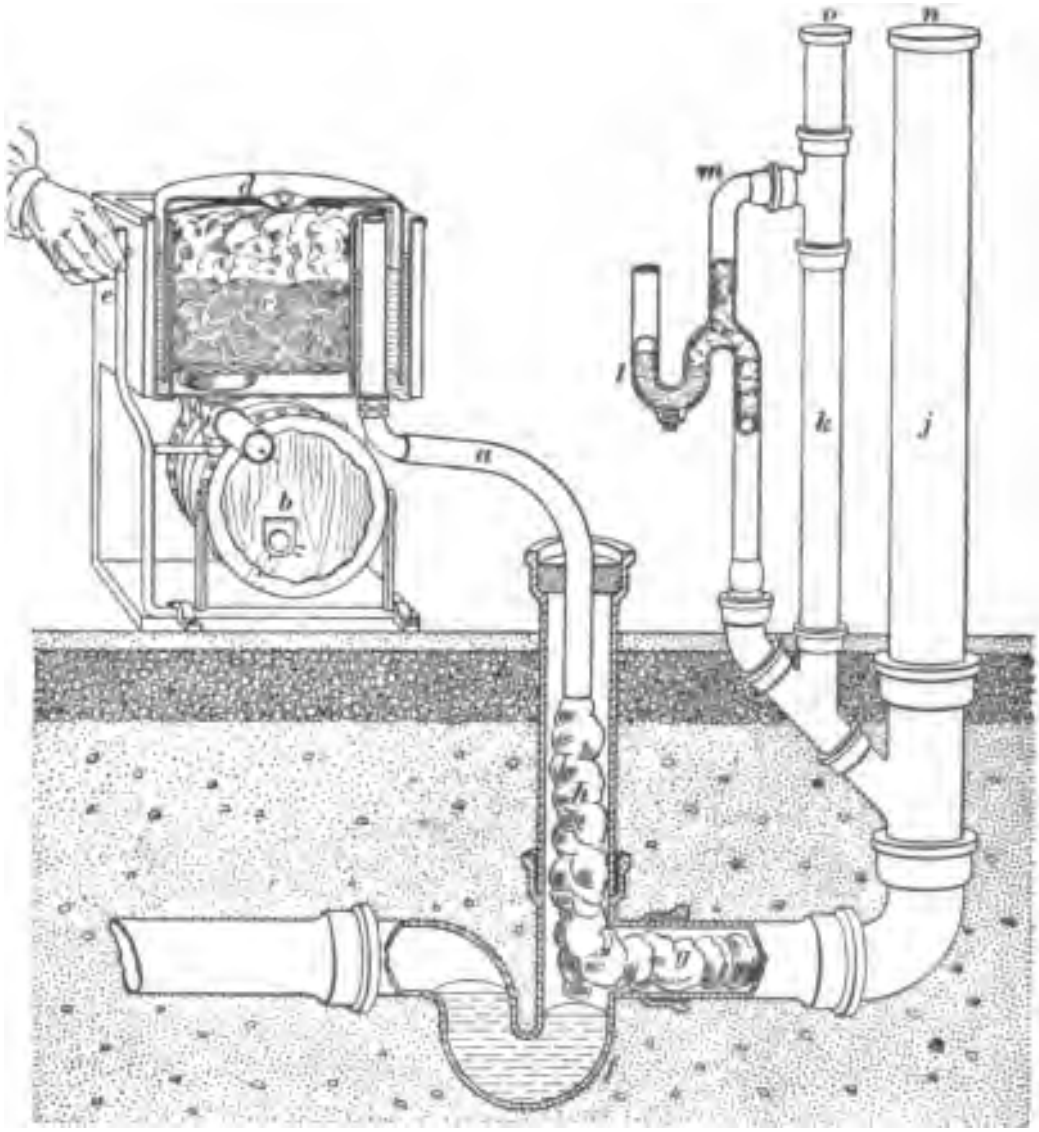
combustion of the mass. Smoke, consequently, is given off from the surface of the fuel (which should be old, greasy cotton waste gathered as scrap from the pipe vise) and is forced down through *a* into the drainage system. The body of greasy waste on top of the smoldering layer of waste acts as a fire-



check by cooling the smoke as it ascends. It is necessary that a thick bed of fuel be used to produce dense, cool smoke.

Let the illustration represent a system of house drains, *f* being the main intercepting trap; *g*, the main house drain; *h*, the fresh-air inlet, *j*, the soil-pipe stack; *k*, the vent-pipe stack; *l*, a fixture trap; and *m*, its back-vent connection; let us

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proceed to test the system with smoke. We leave the tops of *k* and *j* open, and then blow dense smoke into the system. The smoke will fall down *h*, roll along *g*, and then rise up in each of the vertical pipe lines and so push the air ahead of it and out through the open ends on top. When the air is all out, and the smoke consequently blows freely from the open ends in dense heavy clouds, the ends are sealed air-tight by laying in putty a 6-lb. sheet-lead cap over each, as shown at *n* and *o*. The bellows is operated until a pressure is raised in the soil pipes. When the upward pressure on the under side of the drum *d* overbalances its weight, the drum will rise and float in the water. The pressure required to raise the drum is equal to that required to support a column of water about 1 in. high. In the illustration, the drum is floating, a pressure of 1 in. water column is on the system, and the cock *i* is closed, to prevent the smoke escaping into the bellows. The effect of the pressure is also observed on the water in the traps *l* and *f*.

If any leaks are present in the system, they can be detected by smoke flowing from them; if everything is air-tight the drum will continue to float.

If the drum shows no appreciable fall in about 5 or 10 min., the system may be passed as gas-tight.

If the trap seals are not forced with any pressure less than that required to raise the drum, the traps may be passed as being safely sealed.

The smoke machine may be applied to the fresh-air inlet; or to one of the vent pipes above the roof—preferably to the latter, as any smoke that escapes while lighting the fuel cannot enter the building.

Porcelain water closets, particularly those of the siphon-jet type, frequently have kiln cracks and other flaws in the inside walls, and sewer gas will escape through these into the building. The smoke test will reveal these leaks, by smoke flowing into the closet bowls through the flushing rims. Many closets otherwise perfect have these internal leaks.

House-drainage systems should be tested once a year, and a report of the sanitary condition should be furnished after each inspection and test. This action is made necessary by

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the fact that the plumbing is often abused to such an extent as to become dangerous; and settlement of buildings often causes serious leakage of sewer gas.

SANITARY MAXIMS.

1. General water-closet accommodation should never be placed in cellar or basement, but should be located where plenty of daylight and ventilation can be obtained, and should open to the outer atmosphere either direct, or by air-shafts at least 3 ft. square.

2. To prevent damp cellars, subsoil drains should be employed where necessary. They must be effectively trapped from sewers or house drains, and some means must be employed to maintain a seal. A check-valve, or back-water trap should be used to prevent a back discharge of sewage into them, should the drains become choked.

3. The arrangement of all drainage or vent pipes should be as direct as possible.

4. If there is a sewer in a street, every building should connect to it separately.

5. Where the soil is *natural*, the house sewer may be of vitrified earthenware pipe, uniformly bedded and jointed with Portland cement and clean sharp sand. This pipe must run straight, and must have a clear bore.

6. If the soil is filled in or *made*, the house sewer must be of extra-heavy cast iron, asphalt-coated; of wrought iron, galvanized, and asphalt-coated; or of brass pipes, to avoid leakage by a settlement of the earth.

7. When it is necessary to run a private sewer to connect with a sewer in another street, it should be laid outside the curb of the street which the buildings face, not across lots where buildings may in future be erected.

8. The main house drains should be run above the cellar floor when possible, and be secured against the cellar walls, supported upon piers built under each joint, or suspended from the cellar ceiling by adjustable hangers.

9. If house drains must be run under the cellar floors they should be laid in straight runs, and clean-outs or inspec-

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fittings should be placed at each branch or change in direction.

10. All changes in direction should be made with curved pipes or Y branches and $\frac{1}{16}$ or $\frac{1}{8}$ bends.

11. Old drains should never be employed for new buildings unless first examined and tested by the smoke machine.

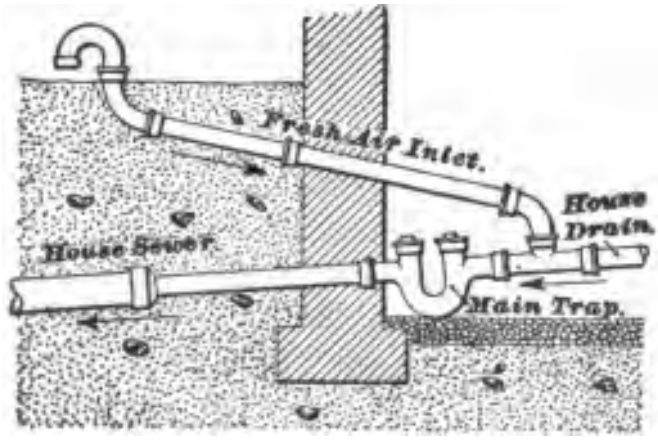

FIG. 1.

12. All house-drainage systems should be disconnected from city sewers by means of a main disconnecting trap, such as is here shown.

If the sewage from a country building delivers into a sea, a river, or open space, the main drain trap may often be advantageously omitted. A fresh-air inlet must always accompany a main drain trap.

13. Fresh-air inlet orifices must be at least 15 ft. from the nearest window or door, and no cold-air box for a furnace should be so placed as to draw air from them.

14. All vent outlets should discharge at least 2 ft. above the highest part of a roof ridge, coping, or light-shaft, and as far as possible away from the light-shaft and all water tanks.

15. Vent pipes above roofs must be 4 in. in diameter or larger, and no cowls or vent caps should be used.

16. Vent pipes passing up through a low roof, and within 30 ft. of any windows in taller adjoining buildings, should be extended to safe points above the higher roofs.

17. All drain, soil, waste, and vent pipes between the main disconnecting trap and the vent outlets must be clear and unobstructed by traps, check-valves, etc.

18. All house-drainage work should be as accessible as possible, being placed either on the faces of walls or in air-shafts. When placed in walls they should be covered by movable pipe boards.

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19. Every fixture in a building must be separately trapped close to each fixture, except where a sink and washtubs adjoin each other, in which case the waste pipe from the tubs may join the inlet side of the sink trap below the water seal.

20. All fixtures and other such traps in buildings should be back-vented by a separate pipe which may deliver into a special back-vent stack at a point about 2 or 3 in. below top of fixture, for tenement or apartment buildings, and at much higher points, if desired, for private-residence work, but in no case at points lower than bottoms of fixtures or bowls.

21. Where lead-waste or back-vent branches connect to cast-iron stacks, the connections must be made with heavy brass ferrules and wiped solder joints; if to wrought-iron or brass stacks, by means of brass-screwed solder nipples provided with a socket to receive the lead pipe and form a flush internal surface. All solder joints in a plumbing system should be "wiped."

22. Special precaution should be taken to secure perfect joints between water-closet traps placed above the floor and the branch soil and vent pipes for same. Brass floor plates should be used for the floor connections. A smoke test is necessary to prove these joints. Back-vent horns on porcelain traps should not be permitted, as they soon break off. The best modern practice is to back-vent the soil-pipe waste close to the floor connection by means of a wiped or screwed joint.

23. Overflow pipes from all fixtures must connect to traps on house side of their seals.

24. All fixture safes should be properly graded to a special waste pipe which must deliver openly at some point, such as a safe-waste sink in the cellar. The outlets of these pipes should be covered with light flap valves.

25. The sediment pipe from the kitchen boilers should not be connected on the outlet side of the sink or other trap.

26. A separate small tank or cistern should be employed to flush every water closet, and in no case should any water closet or urinal be supplied directly from the street pressure pipes when there is any liability of a drawback in the street mains, except by properly constructed flushometer valves.

27. One water closet, at least, should be allowed for fifte-

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inmates of a building. Every story of a tenement should contain at least one water closet.

28. Drinking water should be drawn directly from the street mains. Tank water may be used for washing and bathing purposes.

29. Small tanks should be made of wood, and if placed inside the building should be lined with tinned and planished sheet copper.

30. Larger tanks may be circular and made of cedar staves or wrought iron. Overflow from such tanks should discharge on the roof. Safes are required if inside buildings.

31. Overflow pipes from inside tanks may deliver into an eaves gutter if available, or may be trapped and discharge into an open sink. No pipe connecting to a tank should deliver directly into the drainage system.

32. All rain-water leaders, area water boxes, and subsoil drains, must be trapped from the drainage system, and the seals maintained.

33. In all cases where water comes muddy from the mains, a straining filter should be located in the cellar, to filter all water in the building; muddy water clogs boilers, water-backs, and circulation pipes.

34. A special germ-proof filter is a very valuable addition, and should be placed at a convenient point, to supply water for drinking purposes.

35. Steam-exhaust, blow-off, or drip pipes should not deliver directly into a drainage system. Such water should deliver through a deep seal trap, and at a temperature not higher than 100° F.

36. No privy vaults or cesspools for sewage should be permitted in any place where water closets can be connected with a city sewer.

37. All privy vaults and cesspools should be frequently treated with small quantities of disinfectant, and should be cleaned out thoroughly and often, if water-tight.

38. All architects should see that every drainage system, when completed, is tested with smoke under a pressure of at least 1 inch water column, because the sanitary arrangements are seldom perfect when this final test is neglected.

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PLUMBING FIXTURES.

BATHS.

The most common materials for baths are (*a*) porcelain, or earthenware lined with porcelain enamel; (*b*) cast iron, painted or lined with porcelain enamel; (*c*) tinned sheet-copper lining, inclosed by an iron or steel jacket, commonly called iron-clad baths. Wood-cased tinned copper baths are out of date. Class (*a*) is used in the very finest of work; class (*b*) in plain substantial work; and class (*c*) in cheap work. The two kinds of baths which predominate are the *Roman* shape, which slopes at both ends, and usually has the connections at the back, and the *French* shape, which slopes at one end only, with connections at the foot. French shapes are adapted to corners; Roman, for placing along a wall, away from corners. The following dimensions are taken from a list of baths made by a reputable firm:

DIMENSIONS OF BATHS.

Dimensions.	Roman Shape.				French Shape.			
	* Porcelain.		† Iron Enameled.		‡ Porcelain.		† Iron Enameled.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Length	5	0	4	6	4	6	4	6
Length, including fittings					4	10	4	10
Width outside	2	5	2	5	2	5	2	4
Width, including fittings	2	9	2	9				
Height on legs	2	1	1	11½	2	1	2	0
Depth	1	7	1	7	1	7	1	8
Width of roll rim	0	3		2½	0	3		2½

* A 5′ 6″ bath is the same height, depth, and width of roll rim, but is 1 in. wider.

† The sizes of these baths increase by jumps of 6 in., the other dimensions remaining about the same.

‡ A 5′ bath has same dimensions excepting length; a 5′ 6″ and a 6′ bath are 1 in. wider.

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Porcelain baths are variously classed by different makers, but usually alphabetically; class *a* means perfect, without flaw, warp, or twist; class *b*, slightly imperfect, a little warped or rough in the enamel, but hardly perceptible; class *c*, defective, badly warped, cracked, and blistered.

Marble safes for baths are countersunk to a depth of ¼ in. and are 1½ in. thick; they usually project from 3 to 6 in. beyond the outside line of the bath and its trimmings, and should be nearly flush with the floor.

Spray baths and shower baths, furnished with hot and cold water, should be provided with a mixing chamber and a thermometer, the bulb of which must be located in the center of the current. Spray and shower combinations are supplied by makers to fit their baths, but special ones are also furnished, independent of baths. A countersunk marble or slate floor slab 3 ft. 6 in. square, is usually set under a combination, and the bathroom floor is made water-tight. Porcelain receptors, 3 ft. 6 in. square, 9 in. high, 6 in. deep, with 2½ in. roll rim, are preferable, however. About 20 ft. of brass tubing, closely perforated with very fine holes, is sufficient for a good spray. A shower should not be less than 8 in. in diameter. The height from the floor to shower should be about 7 ft. 6 in. The combination should be provided with a 3″ waste pipe, and a 4″ or 5″ flush strainer in the center of floor slab or receptor.

Seat and foot baths vary in sizes and shapes. The following are dimensions of well-designed roll-rim baths:

DIMENSIONS OF SEAT AND FOOT BATHS.

Dimensions.	Seat Bath.		Foot Bath.	
	Ft.	In.	Ft.	In.
Length	2	3	1	10
Length, including fittings	2	8		
Width	2	2	1	7
Width, including fittings			1	11
Height, front	1	0	1	5
Height, back	1	9	1	5
Depth				11
Width of roll rim		2½		2½

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They are connected with a hot and cold supply and waste connections, the same as plunge baths.

Rain baths are a kind of shower bath, especially adapted for bathing establishments, and have the advantage over plunge baths for such places, in that they occupy but little floor area, and that they are thoroughly hygienic, as the same water never comes in contact with the body twice.

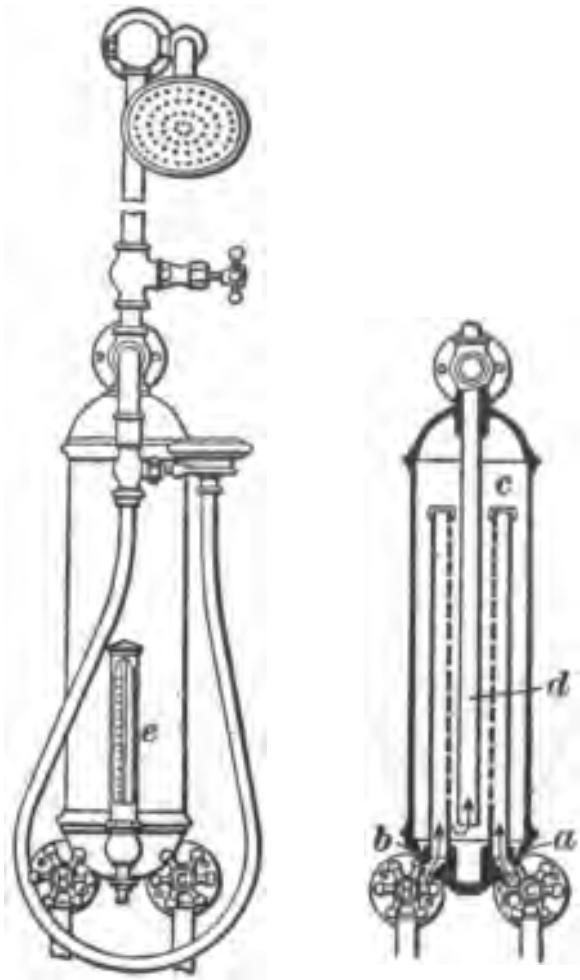

FIG. 3.

In all spray, needle, shower, bidet, and rain baths, and shampoos, a mixing chamber should be used. Such a chamber is shown here; cold water entering through *a*, and hot water through *b*, are admitted to the chamber *c* in small jets and thoroughly mixed before passing into the discharge pipe *d*, the top of which discharges through the shower, or the shampoo attachment as desired. A thermometer *e* has its bulb extending into a circuit of mixing water, to indicate the temperature of the mixture. The difference between shower and rain baths is that a shower falls in large drops at low velocity, and the rain comes in minute jets at high velocity.

Sunken baths are simply large pools sunk below the floor level; they are made of wood, brick, or terra cotta, and are lined with sheet lead or copper, or faced inside with enameled tile. The dimensions and capacity depend upon the size of the room. The depth varies from 2 to 4 ft. Water is usu[al]ly

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provided at the end, from a point above the floor level, as from a nozzle attached against the wall. Waste and overflow connections are provided, similar to ordinary baths.

WASH BASINS.

Wash basins are known as round and oval, and may be had with or without overflow attached. Sizes of round bowls are 10, 12, 13, 14, 15, 16, 17, 18, and 20 in. in diameter, measured from the outside of the flange. Oval patterns are 14 in. × 17 in., 15 in. × 19 in., 16 in. × 21 in. The 16″ round, and the 15″ × 19″ oval basins are generally used. Wash basins should be set near windows, in a position convenient to put a mirror over them, so placed as to have the light from both sides.

Marble basin slabs are 1¼ in. thick, countersunk on top, and have molded exposed edges. Large slabs should be 1½ in. thick. Basin slabs are right or left hand, according as they set in a corner at the right or left hand as a person faces the basin. Backs are usually 8, 10, or 12 in. high, aprons 5 in. deep, and the height from top of slab to floor is generally 2 ft. 6½ in. Corner basins should be provided with back and end plates; ordinary basins, with back plate only; recess basins, with back and two ends. Safes under basins are the same size as the slabs.

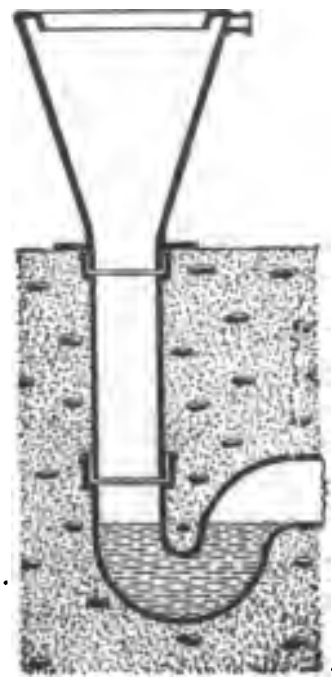

FIG. 1.

WATER CLOSETS.

Pan and Plunger Closets.—These have been condemned by health boards and sanitary authorities for the past 20 years or more, and should never be used; any old ones discovered should be replaced by closets of modern construction.

Hoppers.—Hoppers or washdown closets are designated as *short* or *long* hoppers, according as their traps are above or below the floor. Long hoppers are only used where

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there is danger of the trap being frozen, in which case the traps are placed below frost level. A long hopper is shown in Fig. 1, while Fig. 2 illustrates a short hopper. They can be

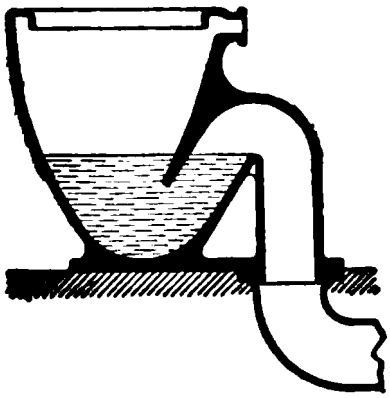

FIG. 2.

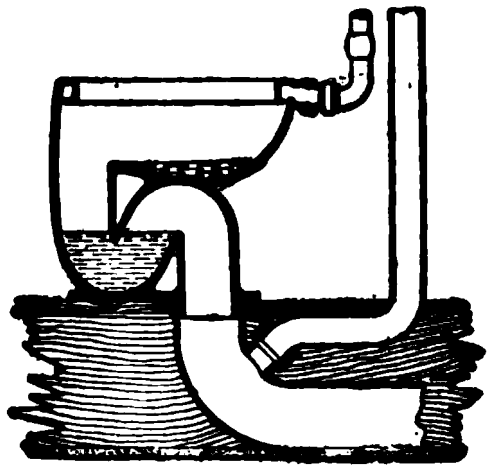

FIG. 3.

had in porcelain, glazed earthenware, or cast iron painted or enameled. Short hoppers are fitted with a flushing tank overhead; long hoppers are usually fitted with a valve below frost level.

Washout Closets.—They consist of a basin and trap, both above the floor. They differ from hopper closets in that the water in the basin is separate from that in the trap, as shown in Fig. 3. They are generally used on good common work, and are thoroughly sanitary; but, being somewhat noisy, are not so desirable as siphon closets for dwellings.

FIG. 4.

Siphon Closets.—They have their contents removed by siphonage through a long crooked outlet, the water in the basin being employed as a trap. They are almost noiseless in operation. There are many kinds of these closets on the market but the most reliable are the simple siphon

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arrangements with flushing rim, as shown in accompanying figure. Those having a low-down tank are the most silent in action. Pneumatic siphon-jet closets are too complicated to be reliable. Fig. 4 shows the closet in action; the dotted lines show the water channels for the flush.

The dimensions of closets vary considerably; the following, however, is good practice:

Width of bowl over all	13 in.
Height from seat to floor	17 in.
Depth from wall to front of seat	23 in.

The distances from the center of the outlet opening to the walls, etc.—or the "roughing-in" dimensions, as they are called—vary with nearly every closet.

Latrines.—Latrines are used chiefly for prisons, factories, etc., and are set up in ranges of two or more, partitions being placed between each latrine, about 24 in. apart. The waste-pipe section is usually 5 or 6 in. in diameter, and the flush pipe 3 or 4 in. They are flushed by a large tank, located about 6 ft. above the seat, the flush pipe being connected to the bottom of the latrines.

Closet Ranges.—Closet ranges, used in schools, factories, etc., are merely large troughs with one outlet and a flushing arrangement. They should be simple and have no mechanical parts to get out of order. There are many different kinds, but the automatic-supply range is probably the best. The combinations are of 3 lengths, 24, 27, and 30 in. between partitions; height from floor to top of seat, 1 ft. 6 in.; height from floor to top of iron partition, 5 ft. 10 in.; depth of partition, 2 ft. 2 in.; width of range, from front to back, 1 ft. 7 in. They can be had painted or enameled. If a hot chimney is near, it is advisable to use local vent-closet ranges, and in such case allow about 15 in. extra length for a ventilating extension.

Closet Seats.—Closet seats should be made of hard wood, and the grain arranged so that the seat will not warp, sliver, or fall to pieces. Quartered oak, in two or three layers crossed, or in one piece with dowels or cross-strips, seems to be the best material. The seat should be secured to the porcelain bowl. The hole should taper from back to front,

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and have the shape and dimensions shown in Fig. 5. The upper surface of the seat should be properly countersunk.

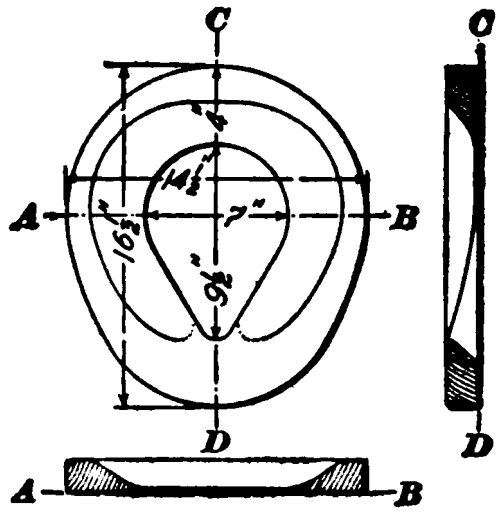

FIG. 5.

Seat Vents.—Many closets are provided with horns above the water-line in the bowl, for the purpose of ventilating the bowl. These are of no use, however, unless a strong, positive draft is constantly maintained in the vent lines. The size of vent pipe is preferably 3 in. for each closet, and not less than 2 in. Two or three closets may local vent into a 4″ pipe, the size of the pipe increasing with the number of closets connecting to it. All closets having horns attached to them for back-venting traps should be discarded, as these horns easily break off. All connections between metal pipes and porcelain should be bolted flange joints, without horns.

Floor Connections.—The ordinary brass-bolted floor flange makes a good connection, but if it is not perfect there is no means of knowing the fact. One of the best floor connections for a closet is shown in Fig. 6. This is a water-sealed floor connection. The pipe *a* is continued 1¼ in. above the finished floor, the end being rounded and free from burrs. The floor is countersunk to receive a supporting flange *b* which is attached to the pipe. A brass flange *c* compresses the rubber gasket *d* against the porcelain when the bolts *e* are drawn up. An annular space is thus formed around the neck of the pipe *a*, which fills with water at the first operation of the closet, thus seal-

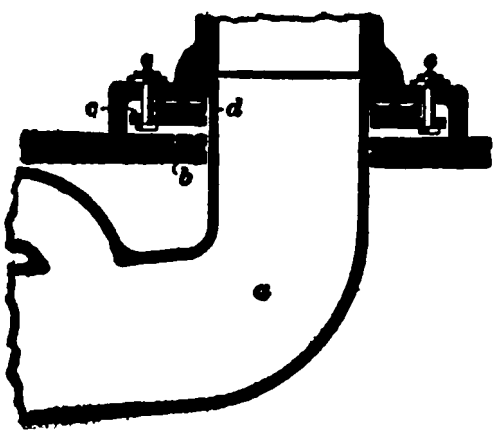

FIG. 6.

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ing the connection. If the connection leaks, this water will run out on the floor; if it does not, gas cannot escape.

Closet Cisterns.—There are a variety of kinds of closet cisterns on the market, some being simple and others complicated. In choosing a closet tank, (1) select for flushing qualities; (2) quietness in action; and (3) simplicity of construction.

Fig. 7 shows a *plain valve* cistern for wash-down closets and hoppers; its dimensions are about 23 in. × 12 in. × 10 in. It is provided with a ball-cock *a* and an outlet valve *b* which is operated by a lever *c* bolted to a cross-bar *d*, the lever being worked by a chain pull. The tube *g* forms an overflow which discharges into the flush pipe *e*. A deafening pipe *f* deadens the noise of the incoming water. The volume of flush from this tank is irregular, depending on the time the valve *b* is held up.

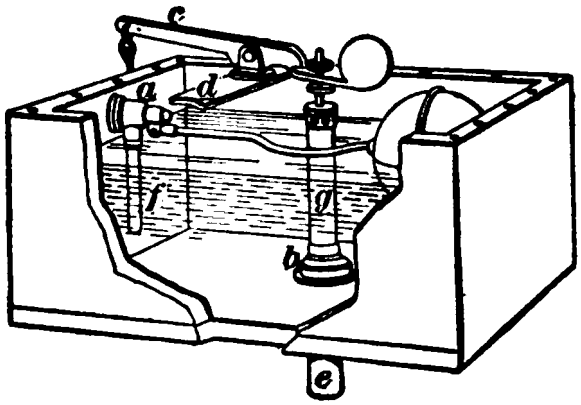

FIG. 7.

A better arrangement is shown in Fig. 8. This is a *siphon* cistern particularly adapted for wash-outs as well as wash-downs and hoppers; its dimensions are about 19 in. × 9 in. × 10 in. A momentary retention of the pull opens the valve *a* and starts the siphon, formed by the shell *b* suspended over, and attached to, an inner standing tube, which is secured to the valve *a*. A *refill* to the bowl is obtained by a slot in the lower end of the siphon tube *o* which causes the siphon to break gradually.

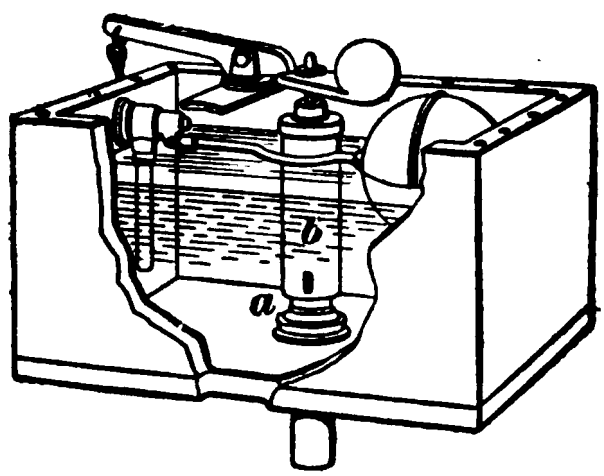

FIG. 8.

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An *after-wash* cistern, shown in Fig. 9, is suitable for seat action. The lever is attached to the seat in such a manner that when the seat is depressed the valve *a* is closed, and the valve *b* opens, causing a flow from chamber *c* into chamber *d*. When the seat is released *a* opens, *b* closes, and the closet is flushed.

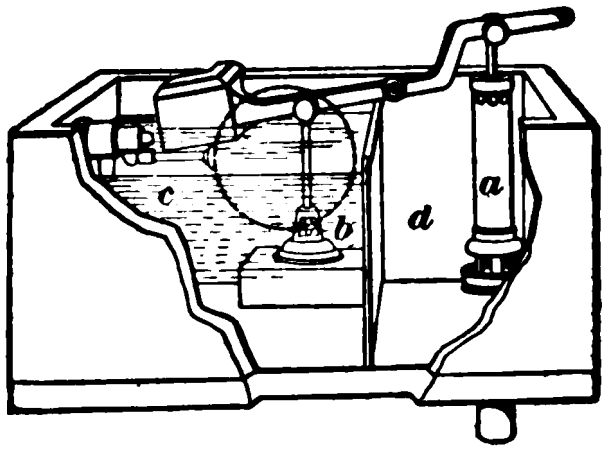

FIG. 9.

A refill *float-valve* cistern especially suitable for siphon-jet closets, and wash-out closets requiring a refill to bowl, is shown in Fig. 10. When the float *a* is raised it remains buoyed up until sufficient water has passed through the closet, when it returns gradually to its seat. The pipe *b* serves as an overflow and at the same time gives an abundant refill to the bowl.

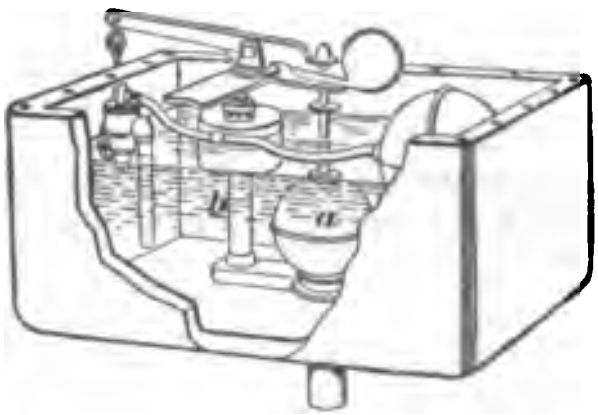

FIG. 10.

These cisterns are remarkably quiet in action. They are made in two sizes. Cisterns with valves away from the edges are preferable, for the wood is liable to warp and cause the lock-nuts to cut the copper.

Water-closet floor slabs are about 27 in. square, and countersunk around the closet. When ordered in a closet combination the hole is cut, and the countersinking done, by the manufacturer. They can be had in Italian or Tennessee marble, and slate. These slabs are sent with unpolished edges and corners, unless otherwise ordered. When the slabs are to be drilled for pipes, a diagram should accompany the order, giving exact distances to centers of openings.

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URINALS.

Urinal ranges are lipped troughs with partitions set 2 ft. apart. They are most satisfactory when flushed by an automatic-siphon tank which discharges through a large jet at the upper end and a spray tube at the back. The tank should be at least 4 ft. above the spray tube. The outlet to trough should be arranged with a siphon which will automatically discharge contents when the supply tank discharges. The period of automatic flushes vary with the water supply; good flushes are obtained if the interval is from 5 to 10 min.

Urinal ranges are made of cast iron, either plain, painted, or, preferably, enameled. The usual dimensions of a urinal range are about as follows: Height of partition, 5 ft. 8 in.; width of partition, about 1 ft. 6 in.; width of urinal, from back to front of lip, 11 in.; depth of trough, 6 in.; regular height of lip, 2 ft.; the height for children is 1 ft. 2 in.

Individual urinals are made of porcelain and are provided with at least two openings, one for the flush and the other for the discharge. The best class have perforated flushing rims, and overflow openings inside. They are known as flat or corner urinals. The best forms are those in which the trap is combined with the bowl, and arranged to be connected without any metal being exposed. The connection between the porcelain and the metal is usually water-sealed, which is advantageous. The waste pipe is provided with a flange and bolt for making a perfect junction with the earthenware. When a flushing tank is used, the combination is simple, efficient, and hygienic.

Individual urinals are set in stalls, the height of which stall should be at least 5 ft. 6 in.; width inside, 2 ft.; length of partition, 2 ft. 4 in.; depth of middle partition, 1 ft. 8 in. Middle partitions stand on nickel plated brass legs about 10 in. high. The size of urinal cisterns should be, for 2 urinals, a 2-gal. cistern; 3 urinals, a 3-gal. cistern, etc.

SINKS.

Sinks are generally classified as kitchen, pantry, slop, and stable sinks, and are made of different materials and in numerous sizes and shapes.

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Kitchen sinks are generally rectangular in plan, and are not provided with plug and chain, or overflow openings. Special kitchen sinks are furnished to order with overflow attachments and plugs.

SIZES OF CAST-IRON KITCHEN SINKS.

(DEPTH INSIDE; OTHER DIMENSIONS OUTSIDE.)

Length. Inches.	Width. Inches.	Depth. Inches.	Length. Inches.	Width. Inches.	Depth. Inches.
16⅛	12⅛	5	30	20	6
18	12	6	32½	18	6
16	16	6	32½	21	6
22	14	6	36	18	6
23	15	6	36	21⅛	6
25⅛	15⅛	6	38	20	6
20	12⅛	6	42	22	6
20	14	6	48	20	6
24	14	6	48	23	6
24⅛	16	6	24	14	8
24	18	6	30	24	8
25⅛	17⅛	6	50	24	6⅛
27	15	6	50	26	6⅛
24	20	6	62	22	8
28	17	6	76	22	7
28	20	6	56	32	9
30	16	6	60	28	10
30	18	6	78	28	10

All sinks should be fitted up open, that is, no woodwork of any description in the form of boxings should be allowed near them, for these boxings become moist and foul, and make breeding places for cockroaches and other vermin. If possible, the walls against which sinks are set should be of glazed tile or other material of a non-porous character.

Sloping drain boards should be provided at every sink. Ash or oak from 1¼ to 2 inches thick are well adapted for drain boards. Sinks that are not cast with sloping bottoms should be set so that the bottom will have a fall towards the strainer. The faucets should be located, if possible, at the end opposite the strainer.

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SIZES OF COPPER PANTRY SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
12	18	5–6
12	20	5–6
14	16	5–6
14	20	5–6
14	24	5–6
16	24	5–6
16	30	5–6
18	30	5–6

SIZES OF PORCELAIN SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
36	23	7
42	24	7
48	24	7
28	18	9
30	20	9

SIZES OF CAST-IRON SLOP SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
16	16	10
20	14	12
20	16	12
24	20	12
30	20	12
36	18	12
36	21	12
23	15	15
36	21	16
48	20	12
48	20	17
60	20	12

SIZES OF EARTHENWARE PANTRY SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
20	14	4½
23	16	5½
25	17	5½

Porcelain sinks can be had with a plain top or roll rim. Copper pantry sinks are made in either square or oval patterns; the former has a flat, and the latter, a round bottom. Sizes for both patterns are given in the table.

Pantry and kitchen sinks should be set 2 ft. 6 in. or 2 ft. 7 in. from the floor to the top of the cap. Slop sinks can be had with or without overflow and plug. These sinks should be set at such a height that the rim will be not more than 24 in. from the floor.

A sink should be located near a window for light, near the pantry or dining room for convenience, and away from the stove for comfort.

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LAUNDRY TUBS.

Laundry tubs, generally speaking, are made of slate, cement, soapstone, glazed earthenware, or solid porcelain. Wood, cast iron or sheet steel are not suitable materials for wash tubs. Tubs used in tenement and apartment houses should be provided with overflows. The height of wash-tubs from floor to top of rim is from 32 to 36 in. The wringer should be set on the right-hand tub.

The following tables give the average sizes of slate and cement tubs:

Slate Tubs.				Cement Tubs.			
No. Parts.	In. Long.	In. Wide.	In. Deep.	No. Parts.	In. Long.	In. Wide.	In. Deep.
1	24	24	16	2	48	21 or 24	16
2	48	21	16	2	53	24	16
2	54	24	16	2	60	24	16
3	78	24	16	3	72	21 or 24	16
				3	80	24	16
				3	90	24	16

Earthenware and *porcelain* tubs come separately, and are connected up singly or in sets of 2, 3, or 4, as required. They are made in two sizes, Nos. 1 and 2, according to the dimensions shown in the following table:

Dimensions.	No. 1.		No. 2.	
	Ft.	In.	Ft.	In.
Length for each tub	2	0	2	7½
Length required for 2 tubs	4	1	5	4
Length required for 3 tubs	6	2	8	0
Length required for 4 tubs	8	3	10	9
Width from front to back	2	1½	2	1½
Depth inside	1	3	1	3

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DIRECT-FLUSH VALVES.

Direct-connected flush valves, as *a* in the accompanying illustration, are now extensively used in place of overhead tanks to flush water closets, urinals, or slop sinks. They may be supplied with water direct from the street service, or, as is generally the practice, from a special tank in the attic. They are made to operate under high or low pressures, but, as a

rule, are not suitable for pressures less than 10 lb. To determine whether a flush valve can be successfully operated from a street supply, first disconnect the service pipe, then turn on the water full force and allow it to run for 10 sec. If the volume of water discharged in that time is not equal to or greater than 5 gal., it may safely be decided that the water

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supply is not sufficient for a direct flush. The sizes of pipes and tanks required under different conditions are as follows:

A 1¼″ pipe from the tank to the closets is usually sufficient for from 1 to 4 closets. If there are more than 4 closets, a 2″ pipe is usually run down to the first lateral, reducing at that point to 1¼ in. for the rest. In large installations, a 2½″ pipe is usually run to first lateral, then reduced to 2 in. and 1¼ in. for the remainder. If the building is quite high, say 10 stories or over, the two lower floors can usually be reduced to 1 in. The size of lateral pipe usually varies from 1¼ in. to 2½ in., according to the number of closets in battery on each floor and the distance from tank. In all cases, take out 1¼″ branches from the laterals, as the valve inlet is usually 1¼ in.

Low-pressure flush valves are used where the tank is less than 20 ft. above the closet. *High-pressure valves* are used where the tank is over 20 ft. above the closet. If the valve closes too slowly, release the regulating screw by unscrewing; if too fast, screw it down a little.

Where possible, the tank should have a capacity of 6 gal. per closet. In large installations, rigid adherence to this rule is not necessary, as 6 gal. per closet provides for two flushes, one immediately following the other. As it is highly improbable that all closets would be used simultaneously, the rule could be modified to suit each case.

SWIMMING POOLS.

An acceptable method of heating small swimming pools is shown in the accompanying illustration. The deep end of the bath is provided with a gutter *a* pitching down to a 6″ or 8″ draining-off pipe *b*, having an enlarged brass strainer sunk flush with the bottom of the gutter. A large-size, domestic, hot-water heater *c* of suitable design, furnished with very large tappings for the pipe connections, is set at a point lower than the gutter *a* and is connected by a 6″ or 8″ flow pipe *d* and return pipe *e* to the bath. A 3″ or 4″ overflow pipe *f* is furnished with an enlarged brass overflow strainer in the

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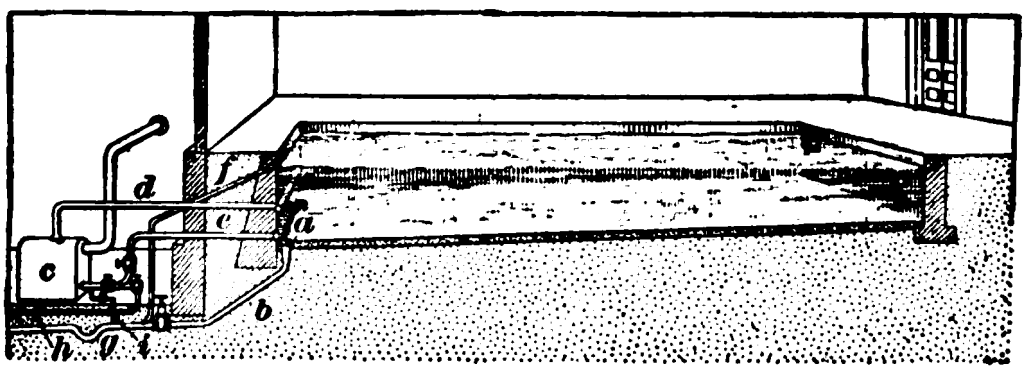
bath. The waste pipe *b* and overflow pipe are disconnected from the sewer by a running trap *g*, which may be ventilated and provided with handholes if desired. A 3″ or 4″ pipe *h* delivers into *e* just as it enters the boiler, and a 1″ pipe *i* drains the boiler into the sewer when desired. To heat the water as it flows to the bath, the upper valve on *e* is first closed and the angle valve shown on the cold-water service pipe *h* is opened until water flows from *d* into the bath. When the bath is full, the supply valve is closed and both valves on *e* are opened, so that the bath water will be free to circulate through the heater. The heater fire may then be dampened sufficiently to maintain the desired temperature. To prevent the hot water from rising to the top of the pool and



to prevent a perceptible hot current near the point where *d* enters the bath, the hot water may be delivered through a perforated pipe running the full width of the bath, as shown. The mouth of *e* may be protected by a brass strainer or by a perforated pipe, as desired.

To compute the size of heater required for warming the water of a swimming pool $20' \times 50' \times 5'$ (average depth), assume the temperature of the cold-water supply to be 45°, and the desired temperature of the bath 65°; also, that when the bath is emptied it must be filled and heated within a period of 10 hr. The temperature through which the water must be raised is $65 - 45 = 20°$. The total number of B. T. U. that must be imparted to $20 \times 50 \times 5 = 5{,}000$ cu. ft,, or $5{,}000 \times 62.5 = 312{,}500$ lb. of water in order to raise its temperature 20°, is $312{,}500 \times 20° = 6{,}250{,}000$ B. T. U., or $\frac{6{,}250{,}000}{10}$

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= 625,000 B. T. U. per hr. A square foot of clean heating surface under the usual conditions will absorb about 2,500 B. T. U. per hr., so that the amount of heating surface required is $\frac{625,000}{2,500}$ = 250 sq. ft. To make allowance for dirty heating surface, sluggish draft, etc., 20 per cent. should be added. Hence, adding 50 sq. ft. to the heating surface already computed, the heater should have 300 sq. ft. of heating surface, or a direct-radiation capacity of about 3,000 sq. ft.

DRAINAGE AND SEWERAGE.

SEWERS.

Drainage is the removal of ground, surface, and storm water.

Sewerage is the removal of sewage.

Separate systems are those in which drainage water and sewage are conducted in separate pipes.

Combined systems are those in which sewage and drainage water are conducted in a common drain.

Separate sewer systems ordinarily need be only about one-twentieth the capacity of combined sewer systems. When laid with but slight fall, separate sewer systems should be flushed with water from automatic flush tanks, placed at the highest points in the system.

Drainage systems and combined sewer systems should be large enough to remove the rainfall from the drainage area during excessive rain storms.

The principal conditions to be considered in designing a system of sewers are as follows:

1. The area, physical outlines, and general topographical features of the district to be drained with reference to the natural flow of water on its surface, in order that the sewers may be located as nearly as possible in the natural drainage channels.

2. The rainfall on the district with reference to the

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maximum intensity of precipitation during a period of time sufficient to completely charge the sewer.

3. The general character, condition, and slope of the surface with reference to the proportion of the rainfall that probably will reach the sewer during the time of its maximum flow.

4. The geological character of the district with reference to the depth to which subsoil drainage is desired; also, with reference to the practical difficulties to be encountered in constructing the sewer.

5. The location of the outlet of the sewer with reference to the final disposition of the drainage and sewage.

These conditions, however, are not wholly independent of one another, and the consideration of any of them will usually involve some consideration of certain features of the others.

RELATION OF FULLY IMPERVIOUS SURFACE TO TOTAL AREA ACCORDING TO DENSITY OF POPULATION.

(*E. Kuichling.*)

Average Number of Persons per Acre.	Percentage of Fully Impervious Surface.			
	Roofs.	Improved Streets.	Unimproved Streets, Yards, Etc.	Total.
15	8.4	3.3	3.0	14.7
25	14.0	7.0	4.3	25.3
32	18.0	10.2	5.0	33.2
40	22.5	14.7	5.4	42.6
50	28.0	19.0	5.6	52.6

In America, it is common practice in designing sewers to provide capacity for 1 in. of rainfall per hr., or 1 cu. ft. per sec. per acre of the district tributary to the sewer, assuming one-half the rainfall to reach the sewers. This is probably a good average practice, but it cannot consistently be adopted

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as a universal standard, for conditions vary in different localities, and a capacity satisfactory for one district may be insufficient for another.

The ratio of storm-water sewage to the total precipitation may be assumed to be the same as that existing between the impervious area and the total area. The relation of fully impervious surface to total area, according to density of population, may be found in the preceding table.

The maximum amount of storm water reaching the sewer from impervious surfaces, in percentage of rainfall, according to Mr. Knauff, is as follows:

On flat roofs.....40 to 50 per cent.
In courts and squares.....50 to 70 per cent.
On steep roofs.....60 to 80 per cent.

These percentages are probably rather low for small areas. In London it has been found from gaugings of the sewers that from 53 to 94 per cent. of the rainfall flows away as storm water.

The velocity of flow in sewers and drains should not be less than 2 or 3 ft. per sec., nor greater than 4 or 5 ft. per sec., if the sewers are of brick and convey storm water. If there is much sand or grit in the sewage, a velocity of 6 ft. or more is liable to wear away the brickwork.

The fall of brick sewers should be about 1 in 240 if possible, though with frequent flushings 1 in 600 may be permitted. When it is less than this solid matter will be deposited which must be removed by manual labor.

Automatic flush tanks, which are usually constructed as shown in Fig. 1, should have discharge capacities equal to those of the sewers into which they discharge; for the separate system, they are commonly constructed with capacities ranging from about 150 to 250 gal. They should discharge automatically once or, at most, twice during each 24 hr. For thorough flushing, the tank should be so located as to give a head, in feet, equal to from one-half to three-fourths the diameter of the sewer, in inches. The head required by this rule could not, however, be readily obtained for the large sewers of the combined systems.

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It may be stated that the problems of both ventilating and flushing are much simplified in the separate system.

Since the capacity of a sewer must be sufficiently great to meet the requirements of a maximum discharge rate during storms, the proper size of a sewer is found by first computing the volume of water, in cubic feet, that must be removed per second during the heaviest rainfall; then, under the proper sewer grade in the table "Capacity of Circular Sewers Flow-

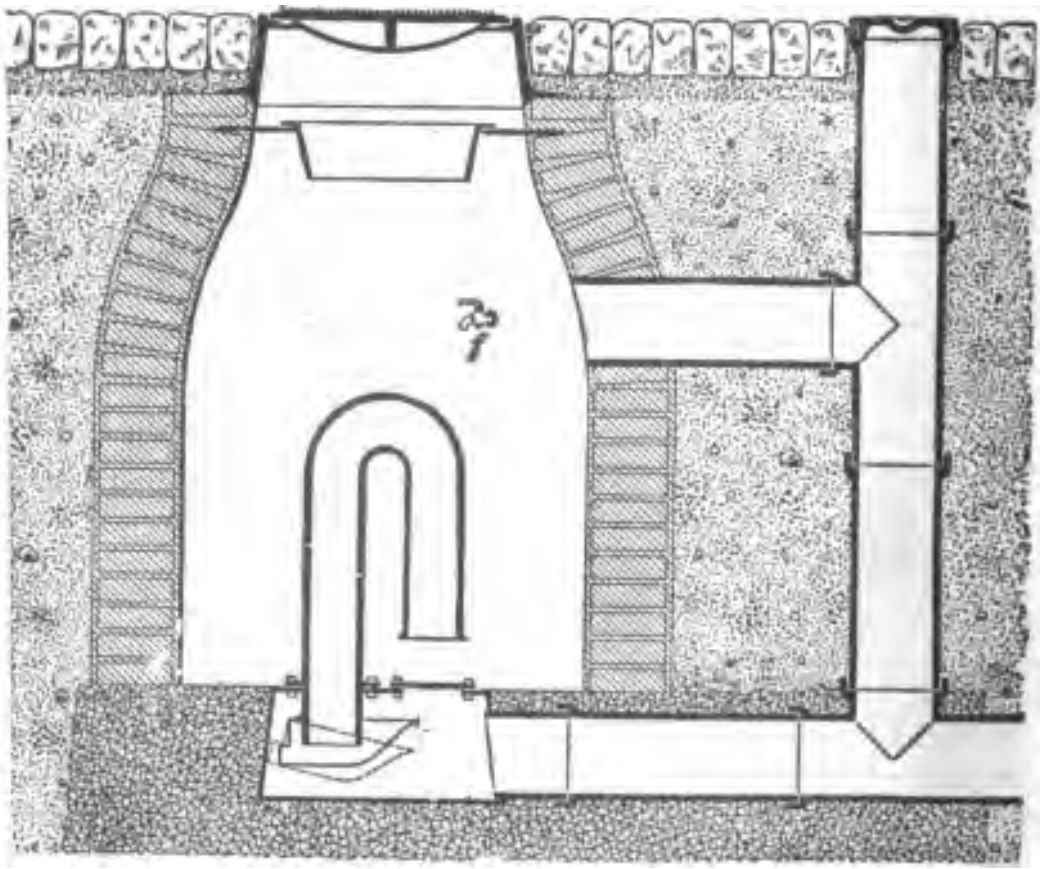

FIG. 1.

ing Full" find rate of discharge nearest to the computed amount to be removed; by following to the column at the extreme left the diameter of the pipe required is found.

Sewers up to 30 in. in diameter are generally constructed of tile pipe; above that size they are constructed of brick or of concrete reenforced with steel.

Fig. 2 shows an egg-shaped sewer.

In terms of the diameter *d*, the egg-shaped sewers should

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CAPACITY OF CIRCULAR SEWERS FLOWING FULL.

(*Wm. Kent.*)

Diameter of Pipe. Inches.	Slope, or Head, Divided by Length of Pipe.						
	1 in 40.	1 in 70.	1 in 100.	1 in 200.	1 in 300.	1 in 400.	1 in 600.
	Rate of Discharge in Cubic Feet per Second.						
5	.456	.344	.288	.204	.166	.144	.118
6	.762	.576	.482	.341	.278	.241	.197
7	1.170	.889	.744	.526	.432	.372	.304
8	1.700	1.290	1.080	.765	.624	.540	.441
10	2.370	1.790	1.500	1.060	.868	.750	.613
11		2.400	2.010	1.420	1.160	1.000	.820
11		3.120	2.630	1.860	1.520	1.310	1.070
12		4.000	3.350	2.370	1.930	1.670	1.370
13			6.180	4.370	3.570	3.090	2.520
18			10.210	7.220	5.890	5.100	4.170
20			13.650	9.650	7.880	6.820	5.570
22			17.710	12.520	10.220	8.850	7.230
24				15.800	13.000	11.230	9.170
26				19.730	16.000	13.960	11.390
28				24.150	20.500	17.070	13.940
30				29.080	24.750	20.560	16.790

be proportioned as follows: Total height $h = 1.5\ d$; radius r of bottom curve $= 1.25\ d$; radius r_1 of sides $= 1.5\ d$.

The salt-glazed terra-cotta invert block *A* should rest on a solid, unyielding foundation of concrete. The spaces *a* within the block, forming continuous channels to the sewer outlet, may be utilized for draining the land.

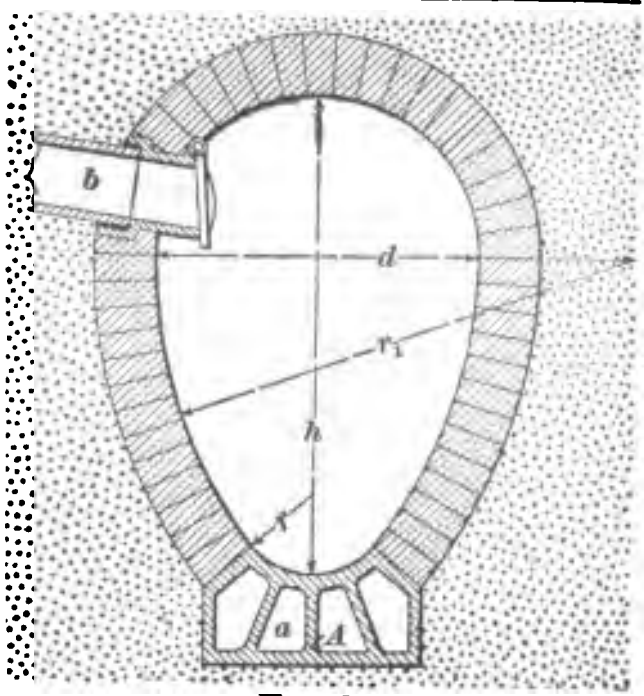

FIG. 2.

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The house drain *b* should join the sewer above the line *d*, as shown, and should be provided with a light, hinged flap valve to prevent water from the sewer backing up in the house drain.

SEWER PIPE.

Sewer Pipe is made salt-glazed and slip-glazed. Salt-glazed pipe is made of a dense clay that vitrifies when fired, and unites with salt thrown into the kiln to form an impervious surface. Slip-glazed pipe is made from a porous clay that does not vitrify when fired; hence, it is covered with a coat of vitreous clay before firing to fill the pores and give it an impervious surface. The slip glazing does not unite with the body of the pipe, however, but forms a thin film over the surface that is easily chipped or peeled off.

COMMON SEWER PIPE.

Inside Diameter. Inches.	Thickness. Inches.	Weight per Foot. Pounds.	Depth of Sockets. Inches.	Annular Space. Inches.
2	$\frac{7}{16}$	5	$1\frac{1}{2}$	$\frac{1}{4}$
3	$\frac{1}{2}$	7	$1\frac{1}{2}$	$\frac{1}{4}$
4	$\frac{1}{2}$	9	$1\frac{1}{2}$	$\frac{5}{16}$
5	$\frac{5}{8}$	12	$1\frac{3}{4}$	$\frac{5}{16}$
6	$\frac{5}{8}$	15	$1\frac{7}{8}$	$\frac{5}{16}$
8	$\frac{3}{4}$	23	2	$\frac{5}{16}$
9	$\frac{13}{16}$	28	2	$\frac{5}{16}$
10	$\frac{7}{8}$	35	$2\frac{1}{8}$	$\frac{5}{16}$
12	1	48	$2\frac{1}{4}$	$\frac{5}{16}$
15	$1\frac{1}{8}$	60	$2\frac{1}{4}$	$\frac{5}{16}$
18	$1\frac{1}{4}$	85	$2\frac{3}{4}$	$\frac{5}{16}$
20	$1\frac{3}{8}$	100	3	$\frac{5}{16}$
21	$1\frac{1}{4}$	120	3	$\frac{5}{16}$
22	$1\frac{5}{8}$	130	3	$\frac{5}{16}$
24	$1\frac{5}{8}$	140	$3\frac{1}{4}$	$\frac{5}{16}$
27	2	224	4	$\frac{5}{16}$
30	$2\frac{1}{8}$	252	4	$\frac{5}{16}$
33	$2\frac{1}{4}$	310	5	$1\frac{1}{4}$
36	$2\frac{1}{8}$	350	5	$1\frac{1}{4}$

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Salt-glazed pipe is the kind most commonly used for sewer construction. The weights and dimensions of various sizes of sewer pipes can be found in the tables of sewer-pipe proportions given.

DOUBLE-STRENGTH SEWER PIPE.

Inside Diameter. Inches.	Thickness. Inches.	Weight per Foot. Pounds.	Depth of Sockets. Inches.	Annular Space. Inches.
15	1½	75	2½	½
18	1⅝	118	2¾	½
20	1¾	138	3	½
21	1¾	148	3	½
22	1⅞	157	3	½
24	2	190	3½	½
27	2¼	265	4	¾
30	2½	290	4	¾
33	2⅝	335	5	1¼
36	2¾	375	5	1¼

LENGTH OF SEWER PIPE LAID WITH 1 BARREL OF CEMENT.

Size of pipe in inches.	6	8	10	12	15	18	20	24
Length of pipe in feet.	1,200	675	450	300	190	130	100	70

ROOF LEADERS.

Roof leaders proportioned as follows have been found, in practice, to give satisfactory results:

For small roofs, 1 sq. in. in sectional area of the leader for each 150 sq. ft. of roof surface. For medium-sized roofs, 1 sq. in. in sectional area of the leader for each 200 sq. ft. of roof surface. For large roofs, 1 sq. in. in sectional area of the leader for each 250 sq. ft. of roof surface.

In cold climates, roof leaders that cannot be exposed to the sun should be located inside buildings. Then, water from the melting snow cannot freeze in the leaders and burst them.

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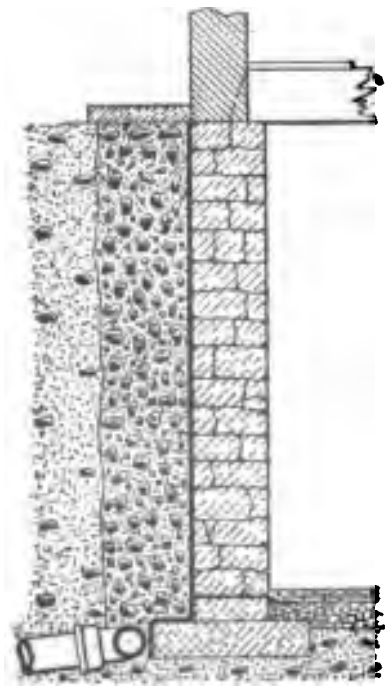
WATERPROOFING WALLS.

Damp cellar walls are due either to water soaking through from the outside, or to wet bottoms, from which water rises in the walls by capillary action. The decay of vegetable matter contained in dirty water generates gases injurious to health, so that the prevention of dampness in walls is a point of great importance. Provision must be made to convey the water away from the walls, as well as to make the latter damp-proof. No earth should be placed against the wall, a 12″ or 18″ space next to it being filled with broken stone or gravel, with, if practicable, an open-jointed tile drain laid at the bottom (see illustration). The outside of the walls and footings should be plastered thickly with 1-to-1 cement mortar; or, preferably, with asphalt and coal tar, mixed in the proportion of 9 to 1, and applied, while hot, about $\frac{1}{8}$ in. thick to the dry walls. The asphalt course should also extend through the walls, as shown at the under side of the concrete floor, which should be 3 or 4 in. thick, and laid on a 6″ or 8″ bed of broken stone. In place of concrete, a very durable composition made of 60 parts of hot asphalt, 10 of coal tar, and 30 of sand, may be used.



The ascent of moisture in walls may be prevented by inserting on the footing course two courses of roofing slate or very hard brick, laid with broken joints in cement mortar, or a few layers of tarred felt may be used.

SEWAGE EJECTION.

Conditions.—In tall office buildings, hotels, underground railway stations, etc., plumbing fixtures are sometimes located below the level of the street sewer. Under such

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conditions the sewage from the floors below the sewer level is collected in a sump, from which it is automatically discharged to the sewer by mechanical means.

The use of pumps for sewage ejectment from buildings is not much favored by sanitary engineers at present, the method of removal by means of compressed air being preferred. When pumps are to be used, however, centrifugal pumps may be selected.

Compressed-Air Ejection.—There are several designs of automatic ejectors for removing sewage by means of compressed air, all of which operate on the same general principle. For instance, they must all have a perfectly air-tight receiving or sump tank, which should be located in a water-tight chamber built of iron or brick. The sump tank must be located at such a level that all drainage from the subsewer system will flow into it by gravity. The inlet pipe must be provided with a check-valve to close when the pressure of air is applied to the tank and open freely by the flow of sewage when the pressure is released. The tank must have a vent pipe that operates automatically, to permit the escape of air after the tank has been emptied, but which closes automatically when the tank is full and the compressed air is applied. There should be an apparatus to automatically open an air valve and admit compressed air when the tank is full and to automatically close the air valve when the tank is empty. A check-valve should be in the discharge pipe from the tank to keep sewage in the discharge pipe from returning to the tank. An air compressor is needed to provide compressed air; also, a tank to receive and store it, and an air pipe from the air tank to the automatic valve on the sump tank. An electric or water motor is required to operate the air compressor automatically when the pressure in the air tank is lowered. The ejectors should be in batteries of two, each being of sufficient size to discharge all the sewage from the drainage system. The motors, air compressors, and air tanks should be located in the engine room or other convenient place, where they are open to inspection and repairs at all times.

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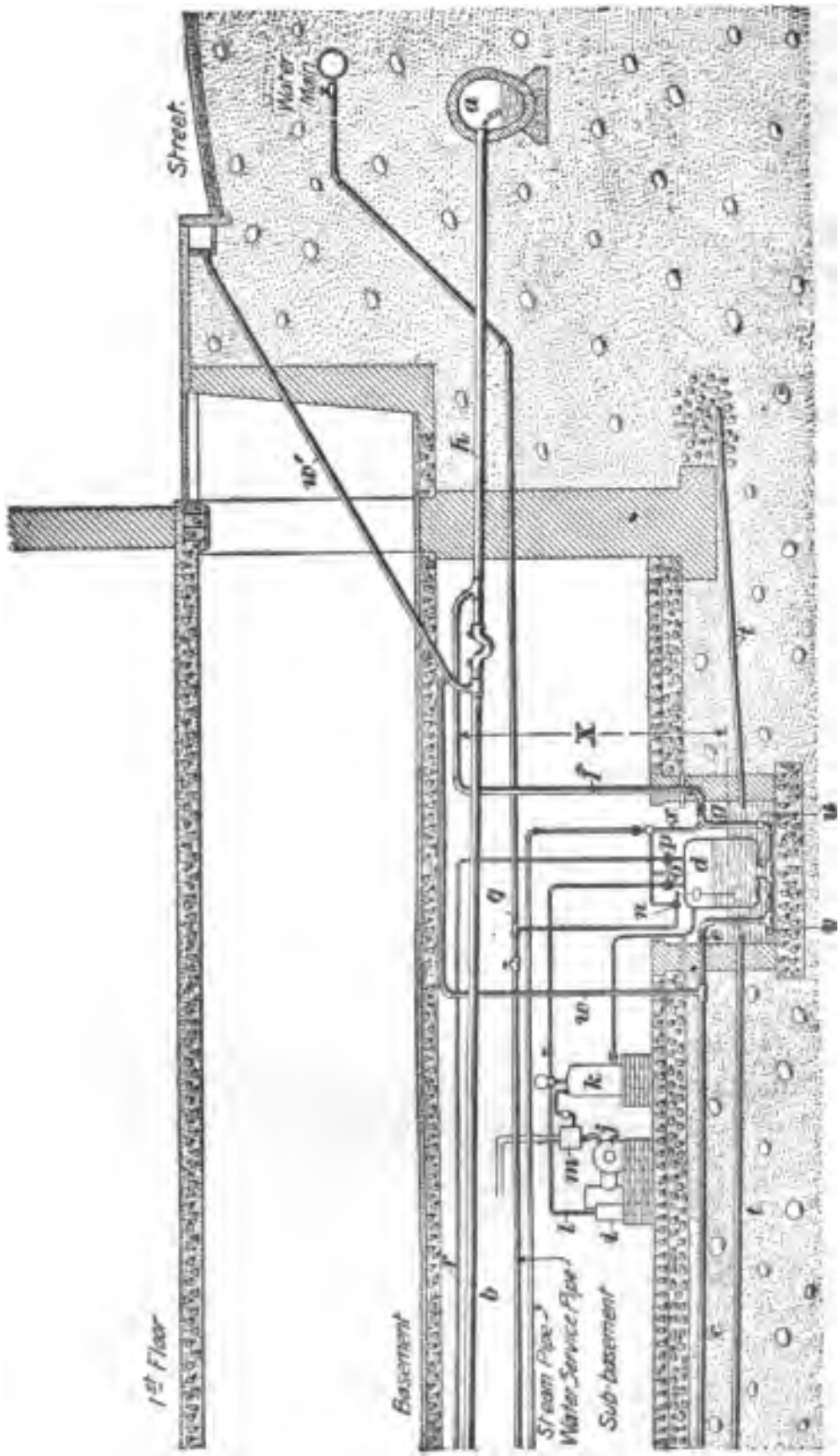

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Sewage Lift.—A device that is commonly used in buildings to raise sewage and discharge it to the street sewer is shown in the preceding illustration, which illustrates the general principles of this apparatus. The sewer is located at *a*; drainage from the plumbing fixtures in the subbasement and subsoil water has to be removed by an ejector or lift. The main house drain *b* is run as low as the sewer will allow, and it takes the discharge from all the fixtures above it, and also the roof water. The subbasement main drain *c* is located just low enough to take the discharge from all the plumbing fixtures located below the sewer level. The lower end of *c* discharges into the bottom of a cast-iron or wrought-iron receiver *d* through a check-valve *e*. A discharge pipe *f* having a check-valve *g* located near the receiver delivers the contents of *d* into the house sewer *h*, the connection being made on the sewer side of the main drain trap shown. An air compressor *i* operated by an electric motor *j* pumps compressed air into an air reservoir *k* through the pipe *l*. An automatic switch regulator and rheostat are located in a casing *m*. A pipe connects the regulator with the air receiver. The pressure carried in *k* is preferably not less than 1 lb. for each foot that the sewage has to be raised. Thus, if the distance *X* is 15 ft., the pressure in *k* must be not less than 15 lb. per sq. in., indicated by the gauge shown on top of *k*. The apparatus will operate with a lower pressure in *k*, but the time required to discharge the contents of *d* to the sewer will be much longer and there will be a liability of the discharges from the fixtures in the subbasement filling *c* before *d* is empty.

The automatic discharging of *d* is accomplished by means of three automatic valves *n*, *o*, *p*. The valve *n* is a hydraulic valve having its inlet connected to the water-supply main *q* by a ¼″ pipe, and its outlet connected to the balanced valve *p* on the vent pipe. These balanced valves work in opposite directions; thus, when the valve *n* is open, water under street pressure opens the valve *o* and closes the valve *p*. This allows compressed air to flow freely into *d*, press down on the surface of the sewage that has accumulated therein, and thus

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force it up through *f* to the sewer; the vent valve *p*, being closed, confines the compressed air in *d*. As soon as the valve *n* is closed, the water pressure is removed from the balanced valves and they reverse their position; that is, the valve *o* is shut and *p* is opened. This action allows the compressed air confined in *d* to escape through the vent pipe *r* to the vent stack. The pressure inside *d* then becomes equal to that of the atmosphere, and sewage can flow freely from *c* to *d*.

The water valve *n* is operated by a stem passing down through the top of the receiver, the upper end of the stem being attached to the balance lever on the valve stem and the part inside the receiver being furnished with a float near the top and a submerged bucket at the bottom. When the sewage has risen in *d* to the level of the float, the stem is raised by the buoyancy of the float and the water valve *n* is opened, allowing the air pressure to force the sewage from *d*. The water valve remains open as the tank is emptied until the water-line falls below the submerged bucket, when the weight of this bucket moves the lever of the valve *n* and shuts off the water from the balanced valve. Thus, it will be seen that the upper float opens the valve *n* and the submerged bucket closes it. The subsoil water from the foundation drains discharges by gravity through the pipes *t*, *t* into the brick sump *u*, filling this sump outside of the receiver; check-valves are placed over the mouth of the pipes *t*, *t* inside the sump to prevent rats from entering the subsoil drains. Sump water flows through the check-valve *v* into the receiver as soon as the air pressure is removed from the receiver, because the water-line in the receiver is then lower than the water-line in the sump. This check-valve automatically closes, however, as soon as the sewage in the receiver has reached the level of the water in the sump. The sump should be covered with movable iron plates laid flush with the floor; the valves *n*, *o*, *p* are usually located under these plates and on top of the receiver.

The advantage in having the subsoil water flow into the sump lies in the fact that should the check-valve *v* leak, the

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water in the sump will become slightly polluted with sewage, which can be readily detected by the engineer. If the subsoil drains were connected directly to the tank, this check-valve might leak sewage back into the subsoil drains without the fact being noticed, and thus saturate the soil under the building with sewage matter, which would be a dangerous condition. Should the check-valve *e* leak, sewage matter from *d* will be forced back to *c* and overflow the subbasement fixtures if the volume of leakage is sufficiently great to fill these lines while the ejector is working.

Presumably the safest attachment that can be used is a sliding gate valve placed close to the check-valve *e* and another one close to *v*; both of these should be operated by a rod attached to a plunger that is moved by water pressure from *n*. Thus, when sewage is being ejected, the gate valve at *e* and *v* will be closed but will open automatically as soon as the pressure in *d* is relieved.

The ventilation of the house-drainage system in the subbasement is accomplished by a fresh-air inlet pipe *w* that connects with the fresh-air inlet pipe *w'* for the plumbing system on the floors above. The back-vent connects to the fixtures of the subbasement, being connected to the vent stack. In this way thorough ventilation of the subbasement plumbing can be obtained.

Should only one receiver be installed, it is essential to have auxiliary apparatus that will discharge the sewage while the air-pressure sewage lift, or ejector previously described, is undergoing repairs. To accomplish this, it is customary to attach a steam-jet ejector at *x* on the discharge pipe from the sump. Without this ejector, should the motor, compressor, or switch be shut down, the tank *k* will lose its pressure and sewage will flood *d* and the basement fixtures while the repairs are being made to the machine. While these repairs are going on, it is necessary only to open the gate valve on the ejector steam pipe, allowing the steam to flow through the ejector *x*. This will lift the sewage from the tank *d* into the street sewer, but will raise the temperature of the sewage presumably about 15 to 20 per cent. When the

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sewage has been sucked out by the steam ejector, cold water will be shut off from an automatic valve on the ejector steam pipe, which will, in turn, shut off the steam from the ejector. The steam ejector, therefore, works intermittently as the tank becomes filled with sewage.

The discharge pipe *f* connects to the sewer side of the main-drain trap to prevent steam accidentally flowing through *f* and entering the drainage system, which would ruin the joints in the system throughout the building if it were allowed to blow up through the soil and vent stacks.

When two or more receivers are employed, the check-valve on one should be weighted heavier than the other, so that the receiver with the weighted check-valve will take the surplus sewage that backs up in the line while the receiver with the light check-valve is being discharged.

Should an air-pressure sewage lift work too slowly to take the drainage, it is necessary only to increase the pressure in the air tank *k*. The average job works under a pressure of about 30 to 40 lb. in *k*, which gives a rapid discharge to the tank.

DISPOSAL OF SEWAGE.

Methods of Disposal.—Sewage from buildings is disposed of chiefly by the following methods: (1) By connection to the street sewer; (2) by cesspools; (3) by direct or indirect discharge to sea, or river, in close proximity to the buildings. The first plan is always adopted in well-regulated cities having a sewer system, and the work is usually done under the supervision of city authorities.

Cesspools.—Where the first and third methods cannot be employed, cesspools are commonly used. They should be built water-tight if within 200 ft. of any buildings or within 100 yd. of any well. Fig. 1 shows common practice in cesspool connections. The main drain from the house is continued through the cellar wall, a trap *a* and fresh-air inlet *b* being placed outside; either a vitrified or cast-iron sewer pipe *c* connects with the cesspool *d*; and a cesspool vent *e* is

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run up the trunk of a tree. A tight-fitting manhole cover should be provided for access to the cesspool *d*.

The size of a cesspool must be determined by the approximate amount of discharge. The least size for a 7- or 8-room house is from 6 to 8 ft. in diameter, and from 10 to 12 ft. deep. The following rule is in common use; For a house with 6 rooms or less, make the cesspool 6 ft. in diameter; for a 7-room house, 7 ft.; increase the diameter 6 in. for each additional room up to 10 rooms; then 3 in. for each additional room up to 20; then 1½ in. for each additional room. The general depth is from 10 to 15 ft. The cesspool should be brick-lined, domed over, and, if possible, provided with an overflow.

Septic-Tank System. Fig. 2 shows a septic tank having two parts: A receiving or settling chamber *a* and a discharge chamber *b*, in which an automatic siphon is placed. The siphon consists of a discharging limb, or deep-seal trap, *c* and an intake bell *d* held securely in place by its own weight over the long leg of the siphon. The sewage flows into the settling chamber through the pipe *e*, the liquid overflowing into the discharge chamber *b* through the deeply trapped pipe *f*. The water gradually rises into the bell *d*, shutting air in the long leg of the siphon. As the water rises in the tank *b*, the pressure on the air confined in the long leg of the siphon gradually forces the water therein to the level shown, when the air is ready to escape around the lower bend *j* of the trap. The distance between the water levels in the two legs of the trap is the same as the distance between the level of the water in the tank *b* and the level of the water within the bell *d*. The column of water in the short leg *g* having the

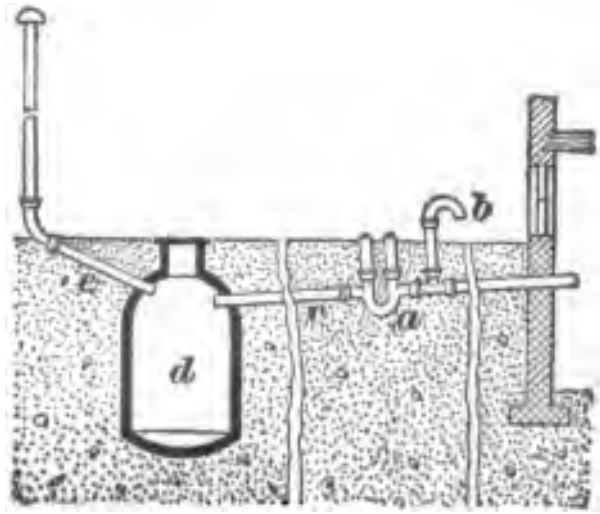

FIG. 1.

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same depth as that of the water in the tank above the level at which the water stands in the bell, the two columns of water balance each other at certain depths. When the depth of the water in the tank *b* is increased, so that a portion of the air confined in the long leg is forced around the lower bend *j* of the trap, carrying some of the water with it in its upward rush out of the short leg *g*, equilibrium is destroyed and the siphon is thereby brought into full action, drawing the water out of the tank until the pipe *h* is uncovered, when the siphonage is broken by the air admitted to the trap leg *c*.

A free escape of water from the short leg of the siphon is insured by arranging the discharge mouth to be a little above

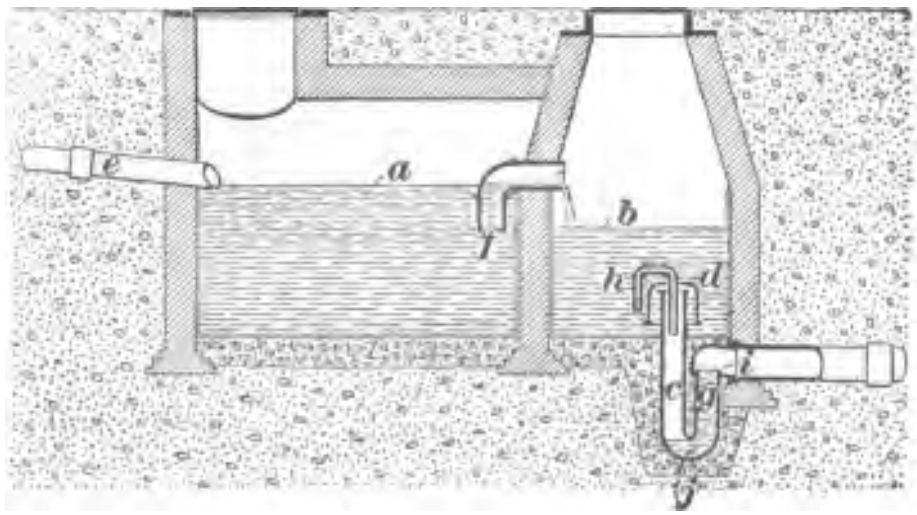

FIG. 2.

the outlet casting *i*, as shown. Between the house and the septic tank and from the tank to the filter bed, where the sewage is finally discharged, glazed-tile piping is used, the joints being well cemented.

The sewage discharged from the septic tank is delivered to a disposal field or subsurface filtration bed, where it is absorbed by the soil. The sewage is carried to the absorption bed through a glazed-tile main distributor from which it flows into absorption drains of ordinary field tile, 3 in. in diameter and 1 ft. in length. The field-tile drains are laid in tile gutters, as shown at *a*, Fig. 3. A $\frac{1}{4}''$ space is left

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between each section of the tile, the space being protected from the entrance of earth by a loose-fitting cap *b*. The gutter and cap are made of a larger radius than the outside of the absorption tile, as shown by the illustration, so that practically the whole joint is available for the escape of

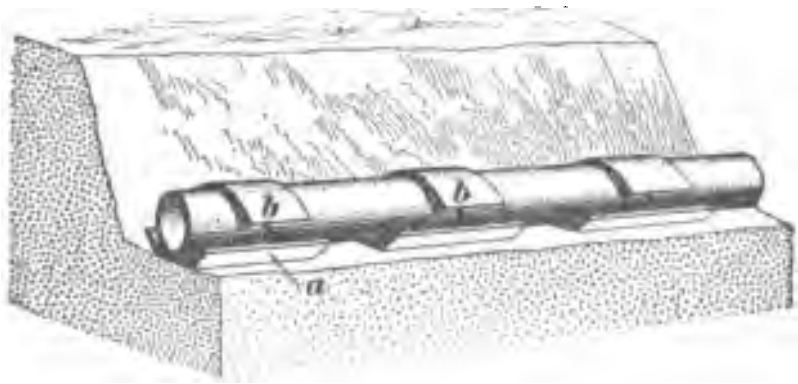

FIG. 3.

sewage into the ground. The gutter *a* is laid about 12 in. under the surface of the ground.

The amount of absorption tile required in a reasonably porous soil is about 1 lin. ft. for each gallon of water discharged from the septic tank. If the soil is heavy the length of the tile should be increased to at least 3 ft. for each gallon in the tank. Clayey soil is not suitable for subsurface disposal by filtration.

The fall of the main drain from the tank after reaching a point within 20 ft. of the absorption tiles should not be more than 1 in. in 25 ft. The absorption lines should have a fall of

FIG. 4.

not more than 1 in. in 50 ft. If a greater fall is given, the sewage may be carried to the far end of the line, where the sewage is liable to break out at the surface.

In designing the absorption bed, the tile may be run in one continuous line, or a number of short-line branches may

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be taken off from the main pipe leading from the septic tank, eccentric Y-branch fittings being used as shown in Fig. 4. As a rule, two disposal beds are employed, the delivery piping to each bed being provided with a gate valve, so that the sewage may be directed to either bed, permitting each a period of rest and thus preventing the field from becoming saturated by the sewage.

When it is necessary or desirable to arrange the disposal field on a hillside, the distributing main cannot be laid to follow the natural surface of the ground because at each discharge of the siphon the sewage would flow with great force

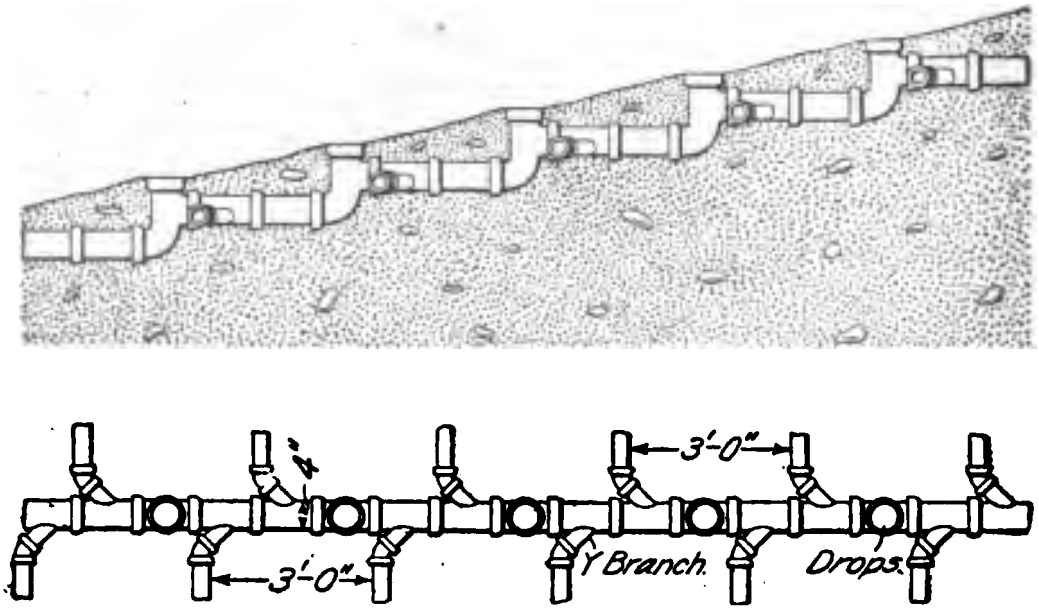

FIG. 5.

directly to the lower end of the bed. This difficulty may be overcome, as shown in Fig. 5, by the use of special drops through which the sewage flows with but little fall. The drops are of vitrified pipe, made in one piece, and having hub and spigot ends. Between the drops are placed special drainage branches. These are also vitrified pipe and are made right and left, as the invert of the 3″ branch is on the same level as the invert of the pipe itself. Thus water flows as easily into the upper branches that supply the upper rows of field tile as it does into the lower branches, and a uniform distribution of effluent to all the field-tile lines is insured.

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WATER SUPPLY AND DISTRIBUTION.

METHODS OF SUPPLY.

Street Service.—The source of supply of water to a building will depend on prevailing conditions and the location of the building. City buildings are usually supplied from city mains, while country buildings are supplied from wells, lakes, and streams, by means of pumps, hydraulic rams, etc.

House pipes should connect to the mains by *corporation stops.* A stop-and-waste cock should always be placed under the sidewalk at the curb and also a separate stop-and-waste cock on the service pipe just inside the cellar wall.

If the street pressure is great enough to force water to the top floor of a building, all fixtures are usually supplied with both hot and cold water by street pressure. If the pressure is too low, or the supply intermittent, a tank is placed in the attic to supply the building. If the pressure is too high, it is customary to apply a pressure regulator in the cellar.

The sizes of street service pipes depend chiefly on the street pressure and the size of building to be supplied. The table "Sizes of Street Service Pipes" gives the common practice These pipes should be increased one size if the pressure is low.

SIZES OF STREET SERVICE PIPES.

Class of Building.	Size of Pipe. Inches.
Single dwellings, two or three stories high	¾ or 1
Larger dwellings	1 or 1¼
Tenement buildings and apartment houses	1¼ or 2
Hotels and factories	2 and up

Pumps.—The amount of water raised by single-acting pumps is estimated by multiplying the number of strokes which the piston travels in one direction per minute by the volume displaced or traversed by the piston in a single stroke, the supposition being that the water flows into the pump barrel

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only when the piston ascends. It has been found, however, that the column of water does not cease flowing when the piston descends, and that the amount of water delivered is greater than usually supposed; in some cases, it is nearly double the theoretical amount.

At sea level a column of water 34 ft. high is balanced by the pressure of the atmosphere, but in practice it requires a very good pump to *draw* to a height of 28 ft.

The height to which hot water can be raised by suction is much less than that of cold water, the height varying with the temperature. This is due to the increased pressure of the vapor. Where possible, the hot water should flow into the pump by gravity. The table "Suction Lifts" gives the theoretical maximum vertical heights of suction pipes for different temperatures.

SUCTION LIFTS.

Absolute Pressure of Vapor. Lb. per Sq. In.	Vacuum. Inches of Mercury.	Temperature. Degrees Fahr.	Maximum Height of Suction. Feet.
1	27.88	101.4	31.6
2	25.85	126.2	29.3
3	23.81	144.7	27.0
4	21.77	153.3	24.7
5	19.74	162.5	22.4
6	17.70	170.3	20.1
7	15.66	177.0	17.8
8	13.63	183.0	15.5
9	11.59	188.4	13.2
10	9.55	193.2	10.9
11	7.51	197.6	8.5
12	5.48	201.9	6.2
13	3.44	205.8	3.9
14	1.40	209.6	1.6

In deep-well pumps, the plunger and valves should be below the water. This will make the pump self-priming in case the valves leak. All piston and plunger pumps, particularly single-action deep-well pumps, should be provided with

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a large air chamber on the discharge pipe, near the plunger, to prevent shocks and preserve the valves. Screw pumps and rotary pumps do not require air chambers because they discharge a steady stream of water. The suction pipe to any type of pump must be air-tight, since otherwise the pump cannot raise the water.

A foot-valve at the base of a high suction pipe will hold it full of water in case a small air leak should develop near the top of the pipe.

In all pumps, whether lifting, force, steam, single-acting, double-acting, or centrifugal, the number of foot-pounds of work performed by the pump is equal to the weight of the water discharged, in pounds, multiplied by the vertical distance, in feet, between the level of the water in the well or source and the point of discharge, plus the work done in overcoming the friction and other resistances. (It is assumed that the water is delivered with practically no velocity.)

To find the discharge of a pump, in gallons per minute:

Let T = piston travel, in feet per minute;

d = diameter of cylinder, in inches;

G = number of U. S. gallons discharged per minute.

Then, $$G = .03264\ T d^2.$$

To find the horsepower of a pump, use the following formula, in which T and d are the same as above, and h is the vertical distance, in feet, between the level of the water at the source and the point of discharge.

$$\text{H. P.} = .00033724\ G h = .00001238\ T d^2 h.$$

In both the above formulas, allowance has been made for friction, leakage, etc.

The duty of a pump is the number of foot-pounds of work actually done for 100 lb. of coal burned.

$$\text{Duty} = 835.53 \frac{G h}{W},$$

where W = weight of coal burned, in pounds.

The Hydraulic Ram.—This machine is employed to raise water to a point higher than the source of supply; it is chiefly used where a large flow of water with a low fall is obtainable, and raises part of the water that operates it. The efficiency

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varies with the ratio of the rise of the discharge to the fall of the drive pipe, about as follows:

Ratio of lift to fall: 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26.

Per cent. efficiency: 72, 61, 52, 44, 37, 31, 25, 19, 14, 9, 4, 0.

To obtain the highest efficiency with any fall, the dash valve should be adjusted to close at the instant the water in the drive pipe has attained its maximum velocity.

A ram having a discharge pipe 80 to 100 ft. long will deliver about $\frac{1}{7}$ the quantity supplied to a height about 5 times the fall; or $\frac{1}{12}$ the quantity supplied to a height of 10 times the fall.

If the pipes are lead, the drive pipe should be of the **A** grade, for diameters up to 2 in., and cast or wrought iron for greater diameters. The discharge pipe, if lead, should be of the **B** grade for rises of 50 ft. or less, and of the **A** grade for rises between 50 and 100 ft. For falls greater than 10 ft. or rises of more than 100 ft. the pipe must be heavier than just given. The length of drive pipe should be from 25 to 50 ft.

SIZES OF PIPE FOR RAMS.

Water Supply to Ram. Gal. per Min.	Size of Pipe.	
	Drive. In.	Discharge. In.
¾– 2	¾	¾
1½– 4	1	¾
3 – 7	1¼	¾
6 –14	2	¾
12 –25	2½	1
20 –40	2¾	1¼
25 –75	4	2

If the discharge pipe is very long (say ¼ mi.), a larger size than given in the table should be used. With a given supply of water under a great fall, the ram need not be as large as for the same quantity of water under a less fall. When large quantities of water are to be raised, it is better to increase the number of rams, in preference to having one of very large capacity. Several rams may be set so as to deliver into one discharge pipe, each having a separate drive pipe. The diameter of the delivery pipe is usually about ⅔ of the diameter of the drive pipe. The highest efficiency of a ram is obtained with the specified length and size of drive pipe when the weight and length of stroke of the valve are properly proportioned.

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WATER STORAGE.

Cisterns.—These are used to store rain water underground, for use in country buildings. For an ordinary house with 8 rooms or less, located in a climate where the rainfall is not less than 30 in. per annum, and where very long droughts do not occur, a brick cistern 5 ft. in diameter and 7 ft. deep will be large enough for a family of 10 people. Larger buildings should be provided with two or more cisterns.

Cistern filters are essential in all cases. Fig. 1 shows an excellent and simple form, which may be built a few feet away from the cistern, and connected to it by the pipe *f*. The filter well is built of brick, laid in 1-to-1 Portland cement mortar, and is divided into two compartments by a partition slab *a* of slate or flagstone. The bottom is inclined so that the sediment will collect at *d*. The chamber *B* has a perforated bottom *b*, on which is placed a course of gravel and then clean sand topped with gravel nearly up to the level of the discharge pipe *f*. Rain water enters *A* through the pipe *c*, and deposits any mud that it may contain at *d*. Any overflow in *A* is discharged through pipe *e*. The water flows upwards through the sand in chamber *B*, which clarifies it. The filter may be easily cleaned by stopping up *f*, pouring water into *B*, and pumping out the mud and dirty water from *A*. Renewal of the filtering material is thus seldom necessary.

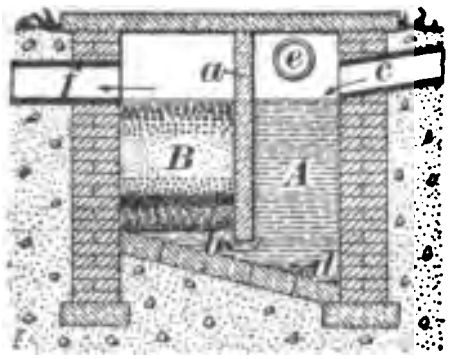

FIG. 1.

House Tanks.—Water-storage tanks located on the roof are generally constructed of cedar or cypress and are slightly conical. They are generally knocked down when shipped, and should be set up and filled with water as soon as delivered. A good solid foundation should be provided for a house tank, and the weight of the tank should not be allowed to rest on the chimes (that part of the stave that projects below the bottom), but should rest on the tank bottom.

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The capacity of cylindrical tanks may be found by squaring the diameter, in feet, and multiplying the product by .7854, then multiplying the area by the height of the tank, in feet. The product will be the capacity of the tanks, in cubic feet. To find the number of U. S. gallons, multiply the number of cubic feet by 7.48.

EXAMPLE.—What is the capacity of a tank 6 ft. in diameter and 5 ft. deep: (*a*) in cu. ft.? (*b*) in U. S. gal.?

SOLUTION.—(*a*) $6 \times 6 \times .7854 \times 5 = 141.40$ cu. ft. (*b*) $141.40 \times 7.48 = 1{,}057.67$ U. S. gal.

The table "Sizes of Wooden Tanks" gives the stock sizes and capacity of ordinary tapered wooden hooped tanks up to 2,820 gal. capacity.

When located within the building, wooden house tanks are commonly made as indicated in Fig. 2. They are usually

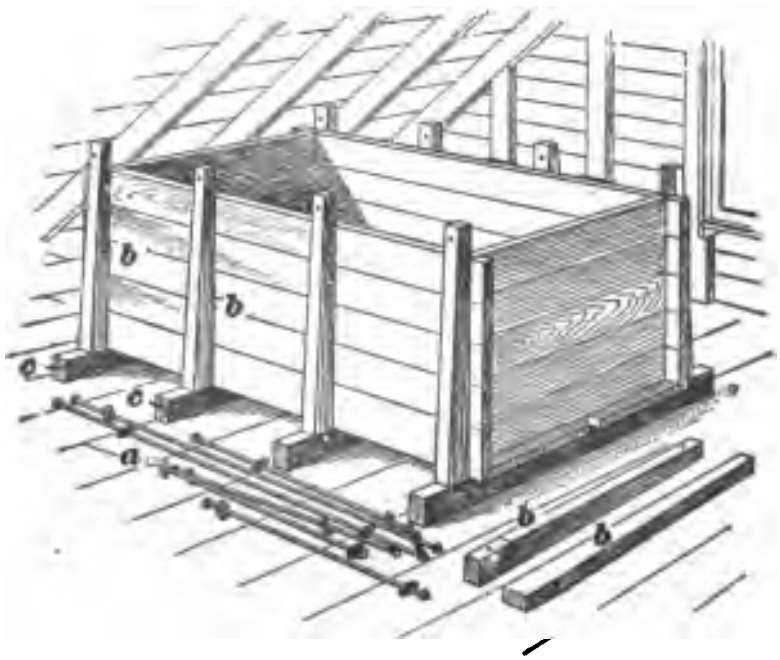

FIG. 2.

lined with sheet lead, or tinned copper. To obviate the use of heavy planking in the construction of such tanks, tie-rods *a* are used to rigidly tie together the end and side braces, or stiffeners *b*, *b*, which are secured by mortise and tenon joints to the timbers *c*, *c* on which the bottom planking of the tank

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SIZES OF WOODEN TANKS.

Inside Bottom Diameter.		Inside Depth.		Capacity.	Approximate Shipping Weight.
Feet.	Inches.	Feet.	Inches.	Gallons.	Pounds.
4	0	1	6	141	234
4	0	2	0	188	283
4	0	2	6	235	312
4	0	3	0	282	342
4	0	3	6	329	372
4	6	1	6	178	290
4	6	2	0	238	324
4	6	2	6	298	357
4	6	3	0	357	384
4	6	3	6	417	441
4	6	4	0	476	461
5	0	1	6	220	314
5	0	2	0	293	352
5	0	2	6	267	411
5	0	3	0	440	440
5	0	3	6	513	491
5	0	4	0	587	529
5	0	4	6	660	580
5	6	1	6	266	360
5	6	2	0	355	401
5	6	2	6	444	454
5	6	3	0	533	495
5	6	3	6	621	548
5	6	4	0	710	589
5	6	4	6	800	645
5	6	5	0	888	686
6	0	1	6	317	404
6	0	2	0	422	445
6	0	2	6	528	504
6	0	3	0	634	552
6	0	3	6	740	611
6	0	4	0	845	659
6	0	4	6	951	720
6	0	5	0	1,057	768
6	0	5	6	1,161	829
6	6	1	6	373	456

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TABLE—(*Continued*).

Inside Bottom Diameter.		Inside Depth.		Capacity.	Approximate Shipping Weight.
Feet.	Inches.	Feet.	Inches.	Gallons.	Pounds.
6	6	2	0	496	504
6	6	2	6	620	568
6	6	3	0	744	616
6	6	3	6	868	683
6	6	4	0	993	731
6	6	4	6	1,117	803
6	6	5	0	1,241	840
6	6	5	6	1,365	985
6	6	6	0	1,489	1,056
7	0	1	6	431	516
7	0	2	0	575	568
7	0	2	6	720	632
7	0	3	0	863	685
7	0	3	6	1,007	743
7	0	4	0	1,151	800
7	0	4	6	1,294	873
7	0	5	0	1,439	926
7	0	5	6	1,583	1,010
7	0	6	0	1,726	1,046
7	0	6	6	1,869	1,114
7	6	1	6	495	564
7	6	2	0	660	622
7	6	2	6	826	696
7	6	3	0	991	752
7	6	3	6	1,156	828
7	6	4	0	1,321	886
7	6	4	6	1,487	960
7	6	5	0	1,652	1,068
7	6	5	6	1,817	1,098
7	6	6	0	1,982	1,156
7	6	6	6	2,148	1,232
7	6	7	0	2,313	1,290
8	0	1	6	564	648
8	0	2	0	752	710
8	0	2	6	940	800
8	0	3	0	1,128	856

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TABLE—(*Continued*).

Inside Bottom Diameter.		Inside Depth.		Capacity.	Approximate Shipping Weight.
Feet.	Inches.	Feet.	Inches.	Gallons.	Pounds.
8	0	3	6	1,316	950
8	0	4	0	1,504	1,010
8	0	4	6	1,692	1,100
8	0	5	0	1,880	1,160
8	0	5	6	2,068	1,221
8	0	6	0	2,256	1,281
8	0	6	6	2,444	1,400
8	0	7	0	2,632	1,432
8	0	7	6	2,820	1,522
8	6	1	6	636	700
8	6	2	0	848	780

is laid. The end braces are drawn together by an iron tie-rod below the bottom as well as by one above the top of the tank. If a tank more than 5 ft. deep is required, the use of heavy braces may be obviated by tying them together by tie-rods running through the middle of the tank and protected from the action of the water by lead slip tubes wiped to the tank lining.

Sizes of house tanks depend on the number of people to be supplied and the probable amount of water each person will use. The amount of water actually required per day has been found by measurement to be about 25 gal. per person. This amount is used approximately as follows:

Drinking	1 qt.
In food	1 qt.
Washing dishes and cooking utensils	1 gal.
House cleaning	2 gal.
Washing clothes	3 gal.
Toilet purposes	5 gal.
Bathing and water closets	13½ gal.
Total	25 gal.

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A horse will drink about 7 gal. per day and will need 4 gal. for washing.

A cow will drink 5 to 6 gal. per day.

A carriage will require 9 to 16 gal. for washing.

Tanks supplied from city mains need not be larger than is required to hold a 2 days' supply. Those that are not near a city and that depend on one pump to fill them should hold at least 1 week's supply. Those that depend on rain only should hold at least enough water to last from one rainfall to the other, that is, from 1 to 6 months' supply.

WATER DISTRIBUTION IN BUILDINGS.

Water Pressure.—When the height, or head, of a column of water is known, the pressure exerted by it at the base of the column may be found by multiplying the head, in feet, by .434; the product will be the pressure, in pounds per square inch.

When the pressure, in pounds per square inch, is known, the head may be found by multiplying the pressure by 2.3; the product will be the head of water in feet.

Sizes of Fixture Supply Pipes.—The sizes of pipe generally used for supplying water to the various plumbing fixtures are given in the following table:

SIZE OF WATER PIPES IN BUILDING.

Supply Branches.	Low Pressure. Inches.	High Pressure. Inches.
To bath cocks	¾–1	½– ¾
To basin cocks	½	½– ½
To water-closet flush tank	½	½
To water-closet flush valve	1 –1¼	¾–1
To water-closet flush pipes	1¼–1½	
To sitz or foot-baths	½– ¾	½
To kitchen sinks	½– ¾	½– ½
To pantry sinks	½	½– ½
To stop sinks	½– ¾	½– ½
To urinals	½– ¾	½– ½

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Capacity of Service Pipes.—The discharge from service pipes and water meters of different sizes, under different conditions, is shown in the table "Capacity of Water-Service Pipes" and its accompanying diagram, Fig. 1. Condition No. 1 represents a discharge at the meter in the cellar;

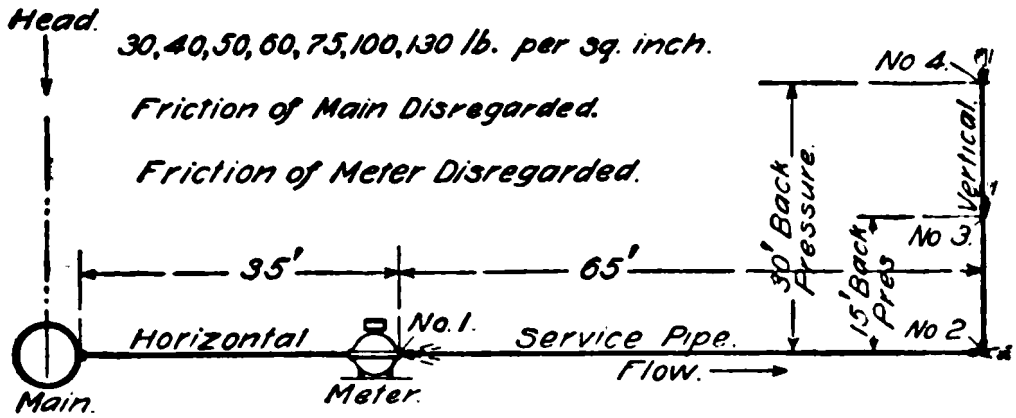

FIG. 1.

No. 2 represents the discharge at the rear wall of an ordinary cellar; No. 3 represents the discharge about on the first floor, and No. 4 represents the discharge about on the third floor of an ordinary building.

Water Measurement.—The quantity of water that passes through service pipes to buildings is measured by means of water meters, a good meter measuring all the water that flows through it, whether it passes as a very small stream or is of the full capacity of the pipe.

The accuracy of a water meter may be tested by weighing the water that passes through it. Several tests should be made, drawing the water slowly in some tests, and rapidly in others. When this has been done, by a comparison of the weight of water that actually passed through the meter with the weight of water the meter dial indicated as having passed, the error of the meter can be determined.

The table "Approximate Deliveries of Water Meters," gives the size by which meters are designated, which is the diameter of their inlet and outlet pipes, and the maximum delivery of water per minute for which they are rated by the National Meter Co.

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CAPACITY OF WATER-SERVICE PIPES.

(Mr. Kuichling's Table of Discharge, computed for The Thomson Meter Company.)

Condition Indicated in Diagram.	Pressure in Main. Pounds per Square Inch.	Nominal Diameters of Iron or Lead Service Pipe. Inches.								
		¼	⅜	½	1	1¼	2	3	4	6
		Discharge, or Quantity Capable of Being Delivered, in Cubic Feet per Minute, From Pipe Under Conditions Specified in Diagram.								
No. 1	30	1.10	1.92	3.01	6.13	16.58	33.34	88.16	173.85	444.63
No. 1	40	1.27	2.22	3.48	7.08	19.14	38.50	101.80	200.75	513.42
No. 1	50	1.42	2.48	3.89	7.92	21.40	43.04	113.82	224.44	574.02
No. 1	60	1.56	2.71	4.26	8.67	23.44	47.15	124.68	245.87	628.81
No. 1	75	1.74	3.03	4.77	9.70	26.21	52.71	139.39	274.89	703.03
No. 1	100	2.01	3.50	5.50	11.20	30.27	60.87	160.96	317.41	811.79
No. 1	130	2.29	3.99	6.28	12.77	34.51	69.40	183.52	361.91	925.58
No. 2	30	.66	1.16	1.84	3.78	10.40	21.30	58.19	118.13	317.23
No. 2	40	.77	1.34	2.12	4.36	12.01	24.59	67.19	136.41	366.30
No. 2	50	.86	1.50	2.37	4.88	13.43	27.50	75.13	152.51	409.54
No. 2	60	.94	1.65	2.60	5.34	14.71	30.12	82.30	167.06	448.63
No. 2	75	1.05	1.84	2.91	5.97	16.45	33.68	92.01	186.78	501.58
No. 2	100	1.22	2.13	3.36	6.90	18.99	38.89	106.24	215.68	579.18
No. 2	130	1.39	2.42	3.83	7.86	21.66	44.34	121.14	245.91	660.36
No. 3	30	.55	.96	1.52	3.11	8.57	17.55	47.90	97.17	260.56
No. 3	40	.66	1.15	1.81	3.72	10.24	20.95	57.20	116.01	311.09
No. 3	50	.75	1.31	2.06	4.24	11.67	23.87	65.18	132.20	354.49
No. 3	60	.83	1.45	2.29	4.70	12.94	26.48	72.28	146.61	393.13
No. 3	75	.94	1.64	2.59	5.32	14.64	29.96	81.79	165.90	444.85
No. 3	100	1.10	1.92	3.02	6.21	17.10	35.00	95.55	193.82	519.72
No. 3	130	1.26	2.20	3.48	7.14	19.66	40.23	109.82	222.75	597.31
No. 4	30	.44	.77	1.22	2.50	6.89	14.11	38.63	78.54	211.54
No. 4	40	.55	.97	1.53	3.15	8.68	17.79	48.68	98.98	266.59
No. 4	50	.65	1.14	1.79	3.69	10.16	20.82	56.98	115.87	312.08
No. 4	60	.73	1.28	2.02	4.15	11.45	23.47	64.22	130.59	351.73
No. 4	75	.84	1.47	2.32	4.77	13.15	26.95	73.76	149.99	403.98
No. 4	100	1.00	1.74	2.75	5.65	15.58	31.93	87.38	177.67	478.55
No. 4	130	1.15	2.02	3.19	6.55	18.07	37.02	101.33	206.04	554.96

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APPROXIMATE DELIVERIES OF WATER METERS.

(*National Meter Company.*)

Size. Inches.	Greatest Quantity per Minute.	
	Cubic Feet.	Gallons.
⅝	1	7.5
¾	2	15.0
1	4	30.0
1	8	60.0
1½	12	90.0
2	20	150.0
3	36	270.0
4	72	540.0
6	120	900.0

Capacity of Water Mains.—The table "Pressure Loss in Water Pipes" gives the pressure loss due to frictional resistance, in pounds per square inch, for pipes of different sizes at different rates of discharge and for a length of 100 ft. The table is useful in estimating the size of straight pipe within its range and of a given length to discharge a given quantity of water with a given pressure loss. Thus, let it be desired to find what size of pipe 1,000 ft. long is required to discharge 500 gal. per min. with a pressure loss of about 2 lb. Then, the pressure loss per 100 ft. is $\frac{100}{1000} \times 2 = .2$ lb. Entering the table on the horizontal line marked for 500 gal. and following to the right, a pressure loss of .25 lb. per 100 ft. is found in the vertical column marked for 8″ pipe as nearest to 2 lb. pressure loss. Hence, an 8″ pipe may be selected.

Kitchen Boilers.—Iron boilers, or hot-water storage tanks, should be galvanized both outside and inside, particularly inside. These boilers are commonly made of mild steel, and are not so durable as the old-time wrought-iron boilers. Many of the poorer grades become pitted very rapidly, and are not to be recommended for first-class work. The

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PRESSURE LOSS IN WATER PIPES.

(Michigan Pipe Company.)

Discharge. Gallons per Minute.	Inside Diameter of Pipe. Inches.														
	¾	1	1¼	1½	2	2½	3	4	6	8	10	12	14	16	18
5	3.3	.84	.31	.12											
10	13.0	3.16	1.05	.47	.12										
15	28.7	6 98	2.38	.97											
20	50.4	12.30	4.07	1.66	.42										
25	78.0	19.00	6.40	2.62		.21	.10								
30		27.50	9.15	3.75	.91										
35		37.00	12.00	5.05											
40		48.00	16.10	6.52	1.60										
45			20.20	8.15											
50			24.90	10.00	2.44	.81	.35	.09							
75			56.10	22.40	5.32	1.80	.74								
100				39.00	9.46	3.20	1.31	.33	.05						
125					14.90	4.89	1.99								
150					21.20	7.00	2.85	.69	.10						
175					28.10	9.46	3.85								
200					37.50	12.50	5.02	1.22	.17						
250						19.70	7.76	1.89	.26	.07	.03	.01			
300						28.10	11.20	2.66	.37	.09	.04				
350							15.20	3.65	.50	.12	.05	.02			
400							19.50	4.73	.65	.16	.06				
450							25.00	6.01	.81	.20	.07	.03			
500							30.80	7.43	.96	.25	.09	.04	.02	.01	
750									2.21	.53	.18	.08			
1,000									3.88	.94	.32	.13	.06	.04	.02
1,250										1.46	.49	.20			
1,500										2.09	.70	.29	.14	.07	.04
1,750											.95	.38			
2,000											1.23	.49	.23	.12	.07
2,250												.63			
2,500												.77	36	19	.11
3,000												1.11	.52	.27	.15
3,500													.70	.33	.20
4,000													.91	.47	.26
4,500														.57	.33
5,000														.79	.41

longitudinal seams are either *single* or *double* riveted; when double riveted, the rivets should be *staggered.*

Copper range boilers are in every case to be preferred, if properly coated inside with block tin. They are classed as *light*, *heavy*, and *extra heavy*, the latter being tested to 150 lb. water pressure. The best forms of copper boilers are those which are reenforced inside by stiffeners or braces so that

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they will not collapse when a partial vacuum is formed within them.

Ordinary steel or iron boilers are tested to 150 lb. water pressure, and extra heavy ones to 250 lb. pressure. The latter should always be used when the street pressure is more than 40 lb. by the gauge, or when water hammer may at any time come on the plumbing system.

STANDARD SIZES OF GALVANIZED BOILERS.

Capacity. Gallons.	Length. Feet.	Diameter. Inches.	Capacity. Gallons.	Length. Feet.	Diameter. Inches.
18	3	12	48	6	14
21	3½	12	52	5	16
24	4	12	53	4	18
24	3	14	63	6	16
27	4½	12	66	5	18
28	3½	14	79	6	18
30	5	12	82	5	20
32	4	14	98	6	20
35	5	13	100	5	22
36	6	12	120	6	22
36	4½	14	120	5	24
40	5	14	144	6	24
42	4	16	168	7	24
47	4½	16	182	8	24

The size of boiler which should be employed for any particular work depends chiefly on existing conditions, such, for example, as the water supply and the nature of the building. A safe rule is to allow a 35- or 40-gal. boiler for a building having one bathroom, and to add 30 gal. additional capacity for every extra bathroom.

In practice it is found that about 100 sq. in. of waterback heating surface in actual contact with the fire is sufficient to give good results with a 40-gal. boiler if water is plentiful, and with a 50-gal. boiler if water is scarce.

Boiler Connections.—These are made in different ways; the most common and reliable method is shown at (*a*) in Fig. 2. The cold-water supply pipe *e* has a branch *f* taken off, to

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supply the boiler. The return pipe *g* furnishes a supply to the waterback *a*, and the sediment cock *h* is used to empty the boiler when necessary. The hot water enters the boiler through the flow pipe *c*, and rising to the top, is conveyed to the fixtures through *d*. The only objection to this arrangement is that it requires a long time for the water in the boiler to become hot, because the hot water continually mixes with the cold. To overcome this trouble, *c* is often connected to *d*

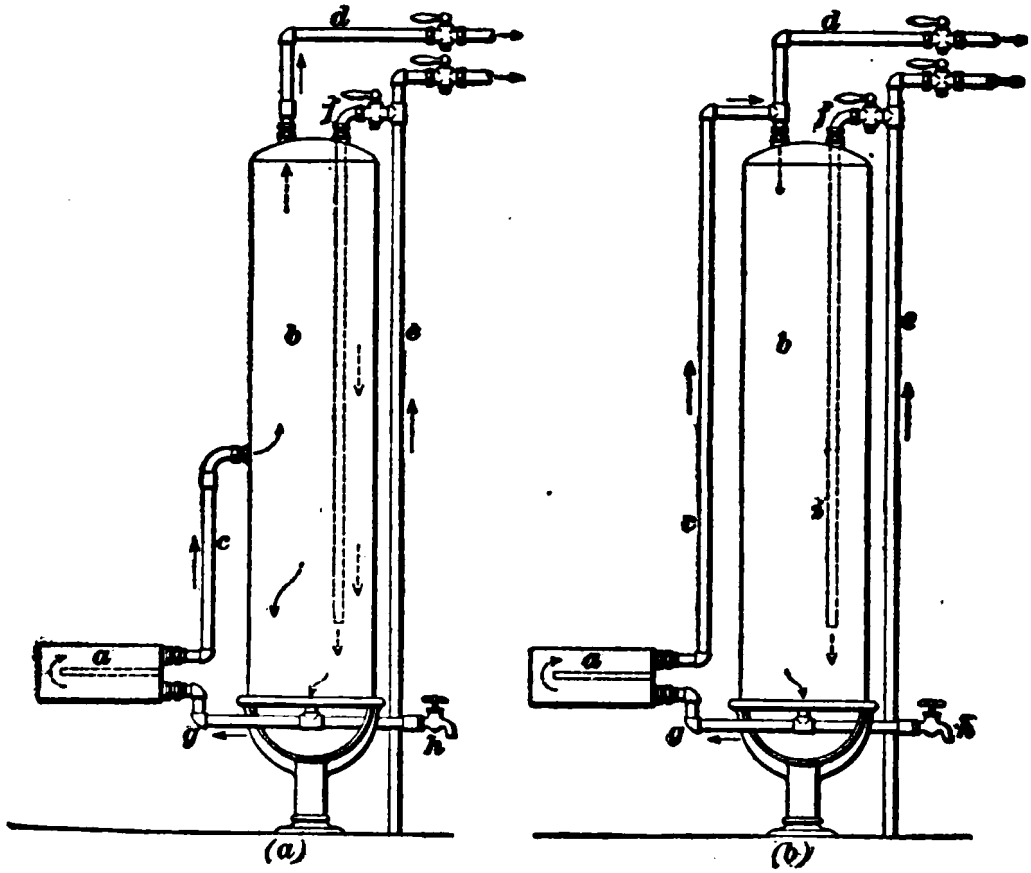

FIG. 2.

over the boiler, as shown in (*b*). But the latter method is also objectionable, in that circulation between the range and the boiler will cease when the service pipe is shut off, because the hot water will siphon down to the vent hole in the top of the inner tube. The waterback will then blow steam through *c* and *d*. To prevent this the pipe *c* may be connected both to *d* and to the side tapping of the boiler.

Multiple Waterback Connections.—Two waterbacks may be

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connected to the same boiler in the manner illustrated by Fig. 3, the heating capacity of the waterback in the kitchen range *a* being supplemented by that of a pipe coil in the laundry stove *b*, so that on washing days the supply of hot

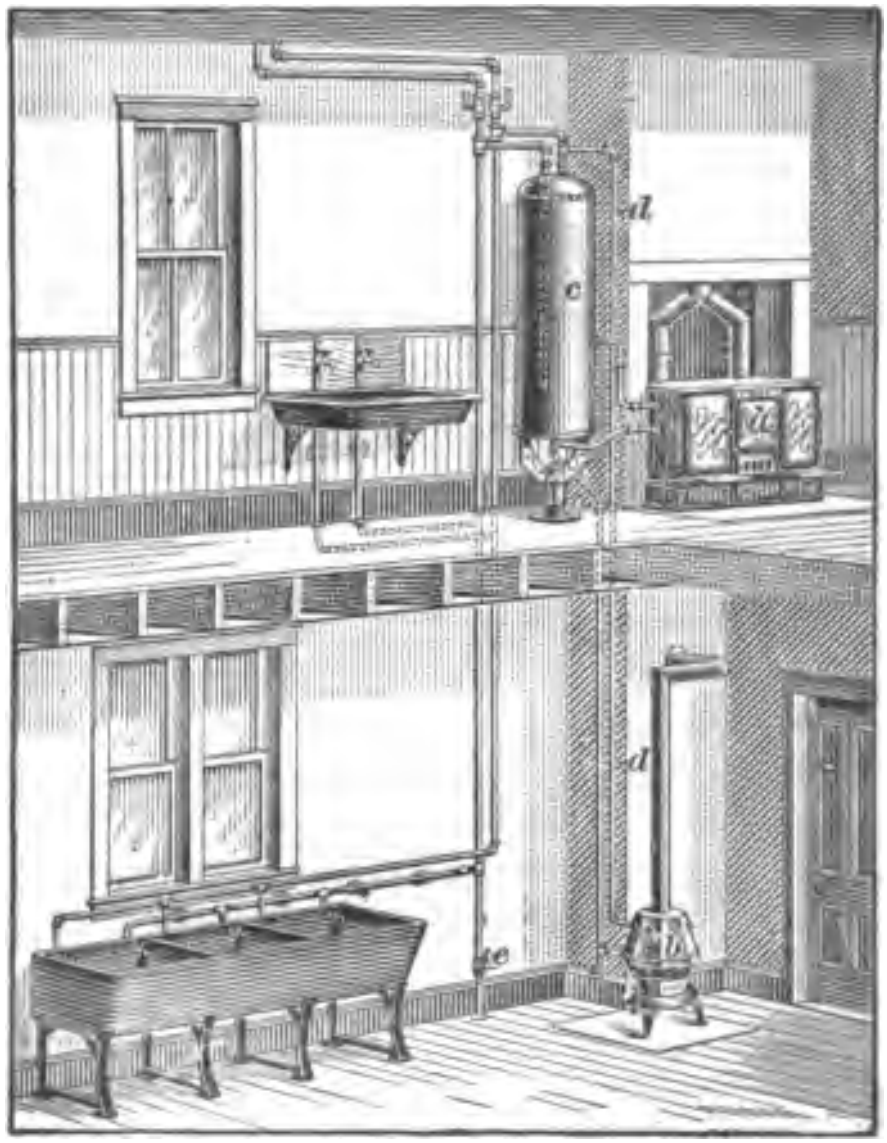

FIG. 3.

water will be sufficient to meet every demand. The connection between the boiler *c* and waterback in the range *a* are made in the usual manner, but the flow pipe *d* from the laundry stove is connected into the top of the boiler, as shown. The cold-water supply may be shut off by means of

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the stop-and-waste cock *e*, the hot and cold water supply to the fixtures on the second floor being controlled by similar stop-cocks in the circulation pipes.

A series of waterbacks *W. B.* may be connected to a boiler, as shown in Fig. 4, so as to secure a positive and efficient circulation between each waterback and the boiler. The arrows show the direction of the currents. To prevent the waterbacks farthest from the boiler from being short-circuited by those nearest the boiler, the pipes are reduced in size, as indicated. In case the side tapping of the boiler is too small, or in case the ranges are set too far apart, and the proper head for circulation cannot be obtained, hot-water flow pipes may be connected to the top of the boiler as shown by the dotted

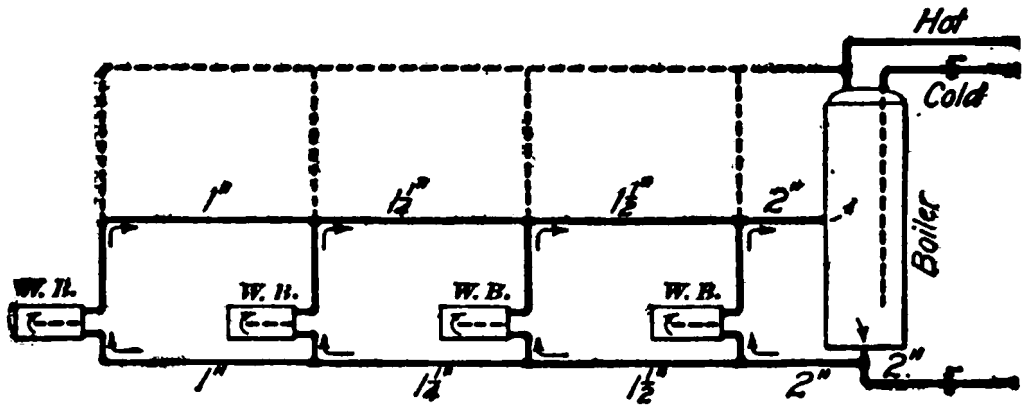

FIG. 4.

lines in the illustration; or, the boiler may be raised so that a satisfactory head may be secured for a connection to the side opening.

Boiler Connections for Heating.—Connections may be made as shown in Fig. 5 for utilizing the water heated by the kitchen fire in warming rooms located above the range boiler. The heated water ascends in pipe *a* and enters the side of the boiler, where it rises to the top of the boiler because it is lighter than the colder water. Cold water from the bottom of the boiler flows through *b* to replace the heated water that leaves the range. The hot water at the top of the boiler flows up the pipe *c* and enters the radiator through the radiator valve shown at the right. It then passes through the radiator,

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gives off heat to the room, and when cooled descends in the pipe *d* and returns to the boiler to be reheated. An air vent placed at *c* will automatically allow air to escape from the radiator. If it cannot thus escape it will accumulate and stop circulation. The pipes *c* and *d* must be graded so as to avoid pockets that would retain air.

Range boiler connections may be made as shown in Fig. 6 for heating the water in winter by means of a hot-air furnace heating coil *a* and in summer by means of a gas heater *b*, a radiator *c* being used to supply heat to the kitchen. The water heater in the furnace must be set and maintained dead level in order to produce good results. By connecting the hot-water pipe from the furnace water heater to the side of the boiler *d*, two distinctly separate circuits are secured, neither one depending on the other for circulation except at the nipple *e*, which can be made 1 in. The connections between the furnace coil and the branches to the radiator and range boiler should be 1¼″ pipe, as shown, the supply and return branches to the radiator being 1 in., and the supply branch to the range boiler ¾ in. The arrows indicate the direction of the circulation of the water through the boiler, furnace, and gas heater. It is advisable to run a hot-water branch from the highest point to supply a wash basin upstairs, so that the air that accumulates at the highest point of the piping system may be drawn off at the basin.

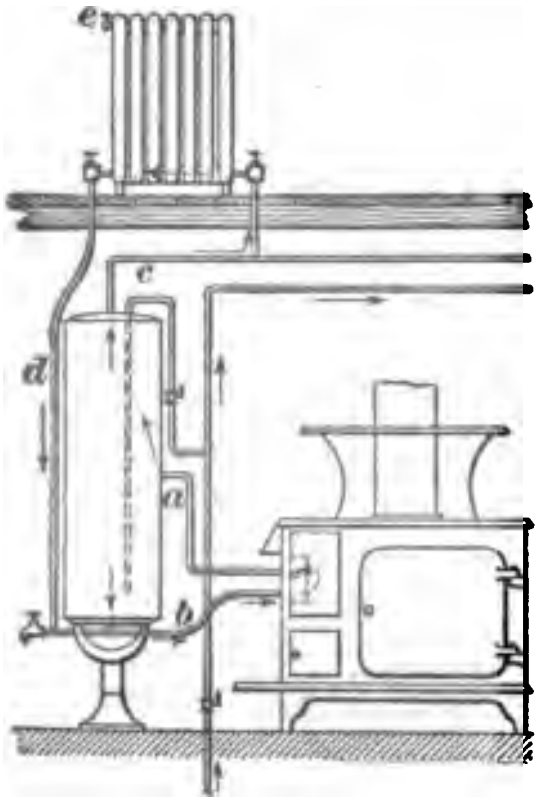

FIG. 5.

Hot-Water Supply to Fixtures Below Range Boiler.—To pipe a

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building so that the hot water can be drawn instantly at fixtures located at a lower level than that of the boiler, it is necessary to form a loop by running the hot-water pipe up as high as possible before descending to supply the lowest fixtures, as shown in Fig. 7. The laundry tubs are located

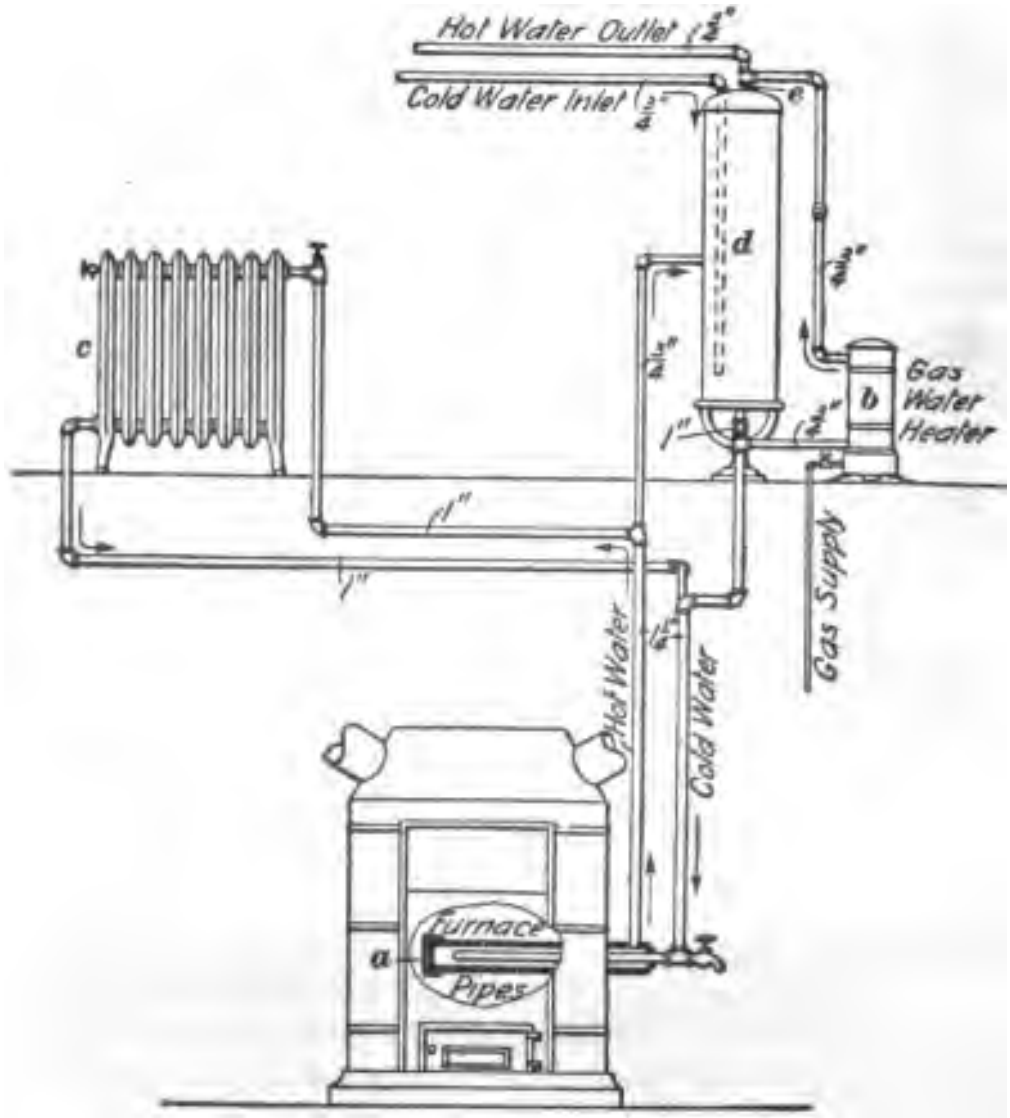

FIG. 6.

in the basement and the system is supplied from a tank in the attic. The hot-water distributing pipe forms a loop, the flow pipe of which connects to the top of the boiler, and the return end to the bottom. A ⅛″ relief pipe is located at *a*, the highest point of the loop. This allows the air to escape

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from the loop, which would otherwise become air-locked. A stop-cock is placed at the base of the relief pipe, as shown, which may, if necessary, be checked down to a very small opening to prevent air from being sucked into the cock while the hot water is being drawn at the fixtures. A check-valve fitted with a very light swinging valve is attached to

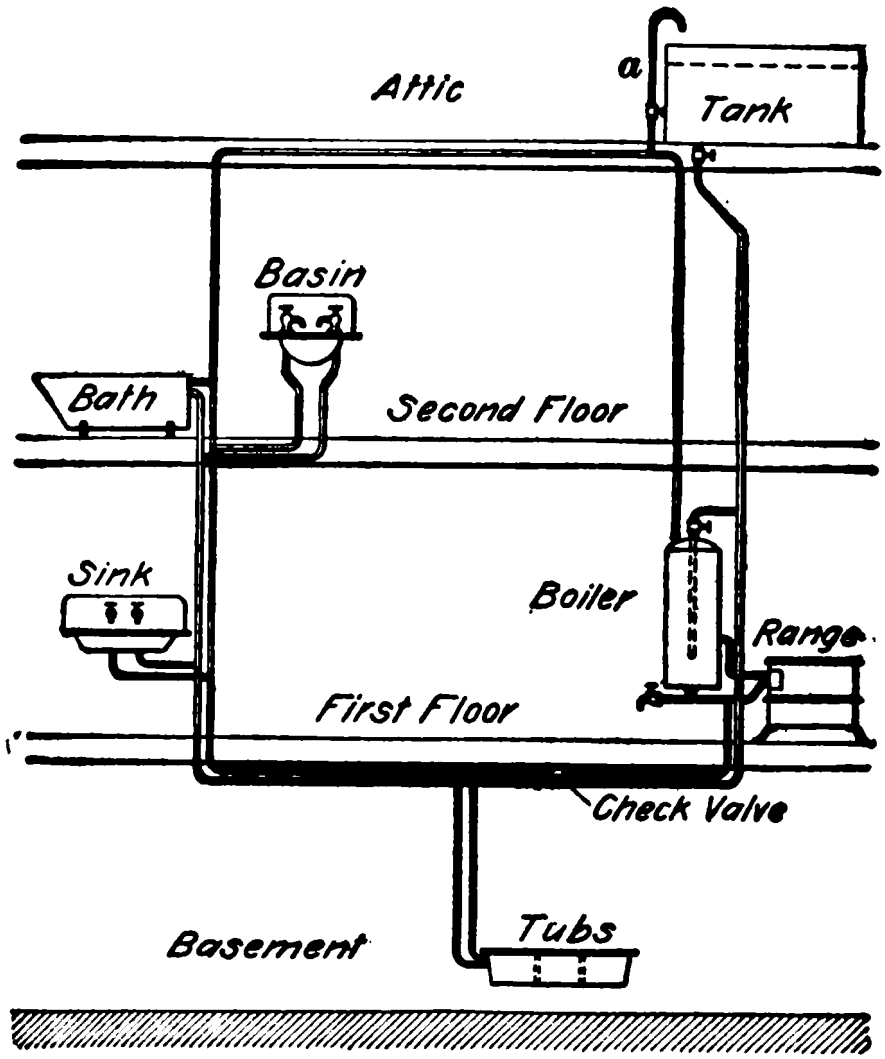

FIG. 7.

the return pipe of the loop as shown, to prevent cold water in the bottom of the boiler from being drawn at the hot-water faucets of the tubs.

Stop-Cock Arrangement.—The symmetrical arrangement of stop-cocks is one of the distinguishing characteristics of an

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expert plumber or pipe fitter. The low-grade mechanic places the stop-cocks anywhere without reference to a neat appearance of the work. The skilled mechanic, who is a neat, tidy workman, arranges them symmetrically and with taste. Fig. 8 shows a neat job in which *a* is the cold supply from the street; *b*, the boiler tube; *c*, hot water to laundry; *d*, a waste pipe from the stop-cocks on the pipes that supply the fixtures upstairs, and the safety valve *e*.

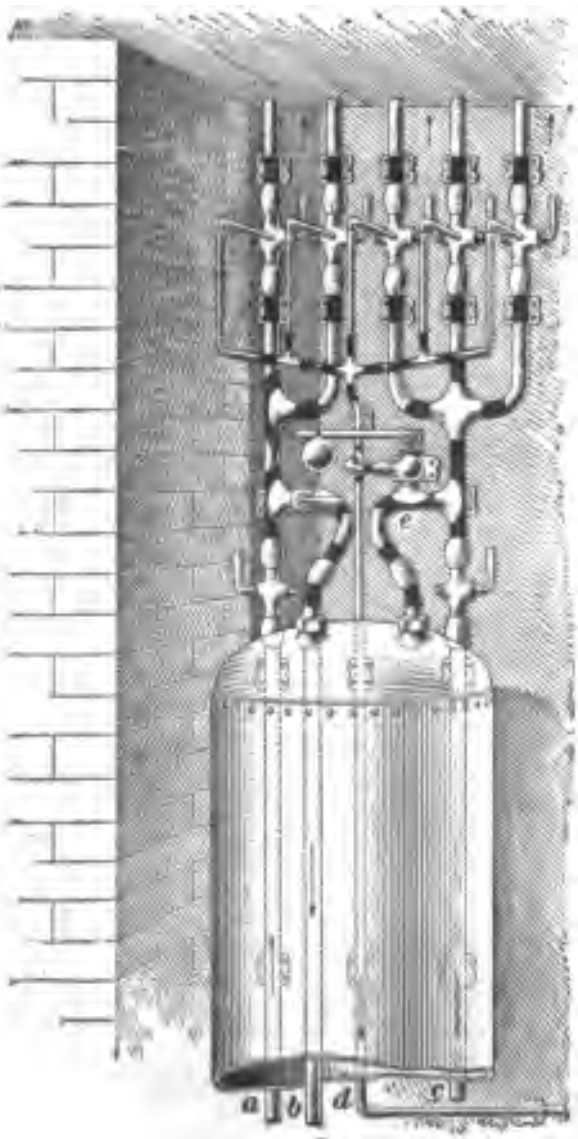

FIG. 8.

Hot-Water Supply Tanks. These are cylindrical in form and are made plain or galvanized, and with or without steam coils. The table "Capacity of Hot-Water Supply Tanks" gives some of the common stock sizes of tanks.

Hot-water supply tanks used where a large quantity of hot water is required are usually provided with steam coils, as shown in Fig. 9. The coil is made from pipes and fittings; steam enters the coil through the pipe *a* and passes into a manifold *b*, whence it passes through the pipes *c*, *c* and return bends *d*, *d* into the manifold *e* and leaves through the pipe *f*. The number of coils to be used depends on the amount of heating surface desired. The pipes *a* and *f* screw into large bushings *g*, *g* threaded outside to fit a tapped hole

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in the shell, and tapped inside to suit the pipe. By substituting different bushings, the size of the inlet and outlet connections is readily changed. The hot-water supply connections are made to the tank at *h*, *h*, and the cold-water service pipe and the drain pipe to the sewer may be connected to the tanks at *i*.

CAPACITY OF HOT-WATER SUPPLY TANKS.

Capacity. Gallons.	Length. Feet.	Diameter. Inches.
250	6	30
325	8	30
400	10	30
475	8	36
600	10	36
700	12	36
1,000	12	42
1,250	12	48

The size of hot-water tanks for apartment houses is usually proportioned to the number of families supplied. When water is to be supplied for all domestic purposes, the capacity may be as in table "Size of Hot-Water Tanks."

When hot-water tanks are to be heated by a steam coil placed inside of the tank, the size of coil to be used can be determined, approximately, by allowing 15 gal. for each

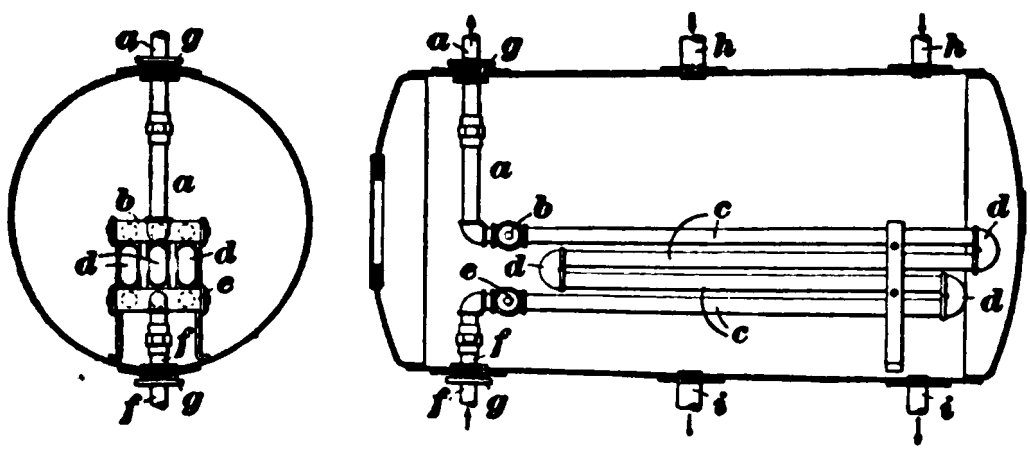

FIG. 9.

square foot of wrought-iron pipe coil surface and 20 to 25 gal. for each square foot of brass or copper pipe coil surface. These proportions have been found to give good results in

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SIZE OF HOT-WATER TANKS.

Families to be Supplied.	Gallons per Family Tank Should Hold.	Total Capacity of Tank. Gallons.
5 to 10	25 to 30	250
10 to 15	22 to 25	375
15 to 20	20 to 22	475
20 to 25	18 to 22	550
25 to 30	16 to 22	650

ordinary work. For determining the size of coils for very large boilers, the following formula and table of heat transmission may be used:

$$S = \frac{Wt}{f(T - t_0)};$$

where S = surface, in square feet, of brass or iron pipe $\frac{1}{8}$ in. thick;

W = weight of water, in pounds;

T = temperature of steam;

t = rise in temperature of water;

t_0 = average increase in temperature of water;

f = factor of 400 for brass pipe $\frac{1}{8}$ in. thick, or 300 for iron pipe $\frac{1}{8}$ in. thick, representing the B. T. U. transmitted per hour to the water from the coil per square foot per degree difference between the temperature of the steam and that of the water.

To the amount of surface found by this formula add about 25 per cent., to allow for condensation of the steam in the coil and the uncertainty of the water circulation. If the circulation of water over the coils is very rapid, a larger amount of heating surface would be required.

EXAMPLE.—How many square feet of heating surface will be required in a brass coil to heat 200 gal. of water per hr. from 50° to 180° F. with steam at 4 lb. gauge pressure?

SOLUTION.—Temperature of steam at 4 lb. pressure is 222.4°; water to be heated is $200 \times 8.3 = 1{,}660$ lb.; rise in temperature of the water is $180 - 50 = 130°$; average temperature of water

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in contact with coil is $\frac{180+50}{2} = 115°$ F. Substituting in the formula $S = \frac{Wt}{f(T-t_0)}$ we have $\frac{1,660 \times 130}{400 \times (222.4-115)} = 4.6$ sq. ft., nearly. Adding 25 per cent. we have $4.6 \times 1.25 = 5.75$ sq. ft., or about 18 lin. ft. of 1″ pipe. Ans.

The amount of heat transmitted from steam to water through metal of different thicknesses, per square foot of heating surface per hour per degree difference in temperature, is given in the table "Heat Transmission Through Metals to Water," with which the factors given in connection with the above formula approximately agree.

HEAT TRANSMISSION THROUGH METALS TO WATER.

Flow of Water per Hour Over 1 Sq. Ft. of Surface. Pounds.	Character and Thickness of Metal. Inches.									
	Brass.					Cast Iron.				
	.1	.2	.3	4.	.5	.1	.2	.3	.4	.5
0	431	379	338	305	278	282	257	235	217	202
500	462	406	362	327	298	299	272	249	230	214
1,000	493	433	386	349	318	315	287	264	243	226
2,000	554	487	434	392	357	348	317	291	269	250
3,000	616	542	483	434	397	382	374	319	294	273
4,000	678	596	531	479	437	415	377	346	319	297
5,000	740	650	580	523	476	432	393	360	333	310
	Mild Steel (Smooth).					Mild Steel (Rough).				
0	368	326	292	265	242	368	326	292	265	242
500	394	349	313	284	260	388	352	316	286	256
1,000	421	373	335	303	278	408	362	325	294	269
2,000	474	420	377	342	313	449	399	357	324	296
3,000	528	467	419	380	348	490	434	390	353	323
4,000	581	515	462	419	383	531	470	422	383	350
5,000	632	573	503	456	417	572	506	454	412	377

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The size of grate, in square feet, required to heat a given number of gallons of water per hour can be found by the formula

$$G = \frac{.001\, g\, t}{l},$$

where G = grate surface, in square feet;
g = gallons of water to be heated per hour;
t = rise in temperature of water;
l = number of pounds of coal per square foot of grate.

WATER FILTRATION.

Water filtration is a straining process by means of which most of the suspended matter in water is removed. The principal methods of filtration are the slow sand process and the mechanical, or rapid, sand filtration. In slow sand filtration the water percolates through a bed of sand and gravel, from 3 to 5 ft. thick, to a system of underdrains below. The rate of filtration in slow sand filters depends on the condition of the raw water, but for average waters a rate of 1,600,000 gal. daily for each acre of filter surface has been found to be a fair average. In mechanical filtration a rate of from 100,000,000 to 200,000,000 gal. of water daily for each acre of filter surface has been found very satisfactory There are two kinds of mechanical filters: pressure filters and gravity filters, either of which may be employed to filter the water used in a building. On account of the convenience with which pressure filters may be attached to the water-supply system, they are more extensively used in buildings than are gravity filters.

House filters should always be connected to a by-pass, so that water can be supplied direct to the fixtures in case the filter is cut out for repair. Most pressure filters are now made with a by-pass forming part of their valve arrangement, so all that is required of the plumber is to make service- and house-supply connections.

The bacteria-removing efficiency of mechanical filters is approximately 95 per cent.

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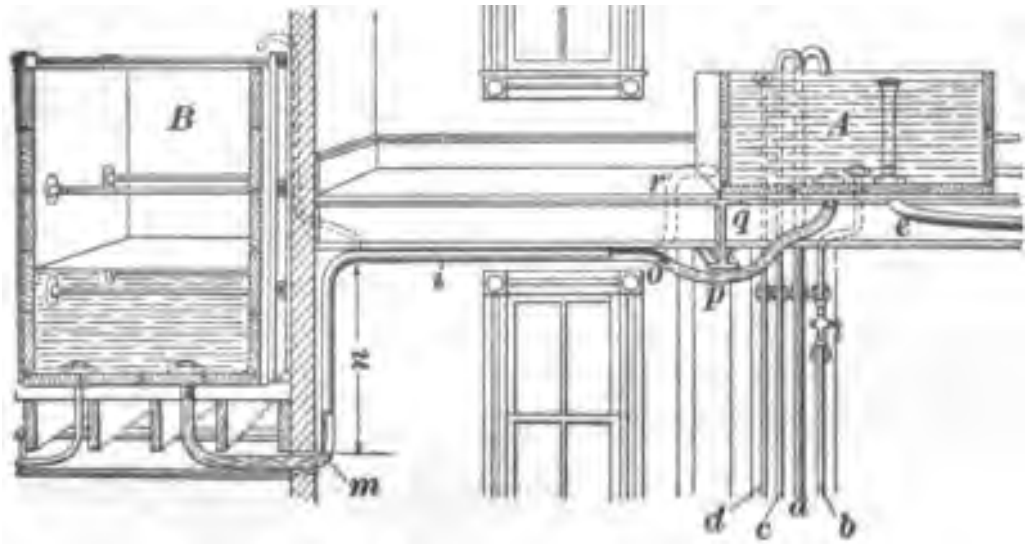
AIR LOCKS IN WATER PIPES.

There are many ways by which house plumbing becomes air bound, but the effects of the air accumulations are chiefly observed in low-pressure systems that are supplied with water by house tanks. The reason of this is that the pressure due to the head between the air locks and the tanks is usually too low to force the air out of the pipes.

A common cause of air lock is that leaden hot-water pipe, run over the floorbeams for a considerable distance, is not supported uniformly throughout its length and hence sags between the beams.

An illustration of air lock in a plumbing system as it



applies to tanks or other vessels depending on one another for their supply, is presented in the accompanying illustration. The tank *A*, which supplies water to the plumbing fixtures, is filled with water by a pump, through the delivery pipe *a*, and is connected up complete with a cold-water distributing pipe *b*, expansion pipe *c*, telltale *d*, and standing waste overflow *e*. Extensions having been made to the building and the tank *A* being too small, the second tank *B* is installed. This tank is set at such a height that its top is level with the top of *A*, and it is supplied with water by a communication pipe *i*, as shown, the supposition being that when *A* is filled by the pump, the tank *B* will also fill up.

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The tanks are so connected, however, that the pipe *i* will be air-locked between the points *m* and *o*, the cause of the lock being the pocket *p*, made in order to clear the lower flange of a steel beam *q*; and the loss of head in *B* will equal the vertical height of the air column as represented by the distance *n*.

There are several ways by which this air lock may be avoided; one method is to make a connection to the side of the tank *A*, as shown by dotted lines at *r*, instead of to the bottom. Another method is to leave the bottom connection as it is, and run in a small air-relief pipe, the upper end of which is bent over the tank *B* and the lower end joined to the highest point of the air bound part of *i*, as shown by dotted lines. Either of these simple changes will effect a permanent remedy.

USEFUL INFORMATION FOR PLUMBERS.

LEAD BURNING.

Lead burning is a process of joining pieces of lead by molten lead instead of soft solder. Ordinarily the edges of the pieces are cleaned and lapped and then fused together by the heat of a hydrogen flame. When it is necessary to reenforce the seam with more lead, the flame is fed from a stick of lead.

A lead-burning machine of the generally accepted form is composed of a hydrogen-gas generator, an air tank, and an air pump. The generator is divided into two compartments, the upper one being open at the top and the lower one closed air-tight. They are joined together by a lead pipe extending nearly to the bottom of the lower chamber. The lower chamber is furnished with a perforated shelf about 2 in. from the actual bottom. Commercial zinc is laid on this shelf through a screw-cap opening placed on top. About 3 oz. of zinc will furnish 1 cu. ft. of gas. The charge of zinc should be about 20 to 25 lb. for a machine that is intended to run all day. A mixture of 5 parts of water to 1 part, by volume, of commercial sulphuric acid, is poured into the upper chamber. This flows into the lower chamber, where it rises until it acts

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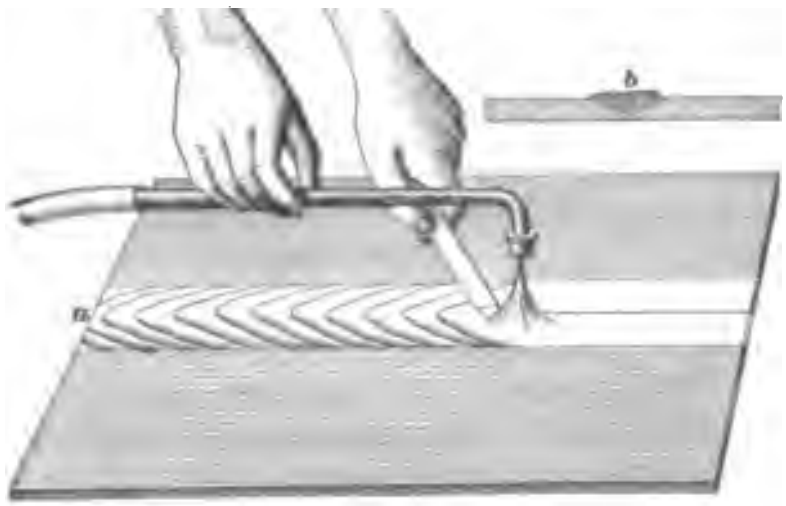
on the zinc, when hydrogen gas is liberated and a pressure is formed in the lower chamber that forces the liquid back into the upper chamber. The column of liquid in the connecting lead pipe forms the desired pressure in the gas chamber. Gas is conveyed to a breeches pipe through a rubber tube, and air from the air holder that is loaded with weights to give the desired pressure is conveyed by another tube to the same



breeches pipe. Two stop-cocks on the breeches pipe are used to regulate the flow of air and gas into the mixing tube, which is generally held in the hand, so that the proportions of gas and air will be just right for a lead-burning flame.

The process of burning is as follows: First, thoroughly clean the edges of the lead to be joined; adjust the blowpipe flame so that it will be about 1½ in. long, needle-pointed, and burning silently. Apply the flame so that the inner cone will touch the surface of the lead. The intense heat will melt the lead and cause the edges to flow together. The flux commonly used for this work is known as Yaeger's salts. Expert lead burners, however, operate without a flux when they use a hydrogen flame. The flux is generally used when an ordinary air-and-gas flame is employed. The illustration shows a good example for practice in lead burning. Two pieces of sheet lead are prepared by planing the edges to be joined straight and square, and shaving the top surfaces clean about ¼ in. wide on each side of the butt joint; then the edges

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are butted together, and the sheets are firmly secured to a board. The flame is then applied, as shown, and it is fed from a lead stick held in the operator's left hand. This stick is about $\frac{1}{8}$ in. or more thick, triangular in section, and shaved clean. With the point of the inner flame a few drops of lead are melted off the stick and allowed to fall squarely on the seam. The flame should instantly follow these drops and fuse them to the sheet lead. A section through the seam, when burned, is shown at *b*. It requires considerable practice to do this kind of work. Repeated failures may be expected at first.

RECIPES, TESTS, AND WORKSHOP WRINKLES.

To Remove Grease From Marble.—Apply to the grease spots a little pile of fullers' earth, or whiting, saturated with benzine, and let it remain 2 or 3 hr.; then wash off.

To Clean Marble.—Rub the marble well with a paste made by mixing with water 5 parts of soda, $2\frac{1}{2}$ parts of powdered chalk, $2\frac{1}{2}$ parts of powdered pumice stone; then wash the slab with soap and water.

Removal of Rust From Iron.—Oxalic acid will dissolve and remove rust from iron without injuring the iron.

Wiping Joints on Tin Pipe.—Joints can be wiped on block-tin pipe by using a solder composed of 3 parts of tin, 5 parts of lead, and 3 parts of bismuth; bismuth solder of this proportion melts at 202° F. The composition and melting point of other bismuth solder can be found in the following table:

Parts of Tin.	Parts of Lead.	Parts of Bismuth.	Melting Point. Degrees, Fahrenheit.
4	4	1	320
3	3	1	310
2	2	1	292
1	1	1	254
2	1	2	236
3	5	3	202

Tin melts at 446° F.

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Cast-Iron Pipe Joints.—These may be made with soft pig lead calked into the hubs, or with rusted iron chips. When rust joints are used, they are made by filling the hubs with a cement made with 18 parts of water, 2 parts of sal ammoniac, 80 parts of iron chips.

To Galvanize Cast Iron.—First, cleanse the casting thoroughly by immersing it, for a few hours, in a bath of 1 part of muriatic acid and 2 parts of water. Then remove the casting and scrub thoroughly with a brush and fine sand, after which wash with hot water. When the casting is clean, dip in a solution of sal ammoniac and hot water, ½ lb. of the sal ammoniac to the gallon. Dry quickly and dip in zinc bath.

To Galvanize Wrought Iron.—Immerse in a bath, consisting of 1 part of muriatic acid and 4 parts of water, long enough to break up the scale; remove from the bath and clean with brushes or scrapers until the surface is free from scale or dirt. Then dip in another bath of muriatic acid and water consisting of 1 part of acid to 4 parts of water, with 1 oz. of sal ammoniac to the gallon of solution. Dry quickly and thoroughly in a hot oven or on hot plates and dip in a zinc bath.

Zinc for galvanizing should be so heated that it will have a clear, shining surface. The dross should be skimmed away and a little powdered sal ammoniac sprinkled on the surface occasionally to clear it.

If the surface of the iron is oily, first boil it in caustic soda or lye, to remove the oil. Then dip it in the muriatic-acid solution to remove the scales. Care should be taken to see that no moisture remains on the article to be dipped. Very little moisture will cause an explosion of steam bubbles that will scatter the molten zinc in all directions.

To Tin Iron Castings.—Cleanse the castings by immersing in a bath of diluted sulphuric acid mixed in the proportion of 1 part of acid to 20 parts of water, and scour with sand if necessary. After cleansing, boil the castings in a concentrated solution of stannate of soda with a quantity of granulated tin.

To Tin Wrought Iron.—Wrought iron is tinned by first removing the scale, and then immersing the articles in a

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pickle of sulphuric acid, finally dipping the iron in a pot partly filled with pure tin, over which is placed a layer of palm oil or tallow, to protect the tin from the action of the air and act as a flux. When the articles have been thoroughly coated, they are removed and allowed to cool, after which any grease is removed by rubbing in bran. Such small articles as rivets and tacks are taken out of the melted tin with a perforated dipper and the melted tin allowed to drain off, when they are thrown against a perpendicular sheet of iron to remove any superfluous tin that may adhere.

Paint for Galvanized Iron.—To prevent paint from scaling off galvanized-iron surfaces, the iron should be exposed to the weather long enough for the grease to wear off, after which it should receive a coat of paint mixed as follows:

Raw oil	1 gal.
Boiled oil	1 gal.
Liquid dryer	½ gal.
Dry metallic paint	20 lb.

To Color Solder.—Soldered seams on copper can be colored to match the copper by brushing the seam with a preparation made of ½ pt. of water to 1 oz. of sulphate of copper in crystal form.

Plumbers' Soil.—To make plumbers' soil, dissolve 2 tablespoonfuls of glue in 1 qt. of boiling water, or stale beer, and beat into the mixture 1 lb. of lampblack and a tablespoonful of powdered chalk. Heat the soil each time it is used.

Plumbers' Paste.—Mix flour and water quite thin, beating all lumps out. Sprinkle a little pulverized alum, which will preserve the paste a month or more. Thicken slowly over a fire.

Simple Tests for Sewer Gas.—Sewer gas is a mixture of several gases that emanate from decomposing animal and vegetable matter in sewers. The principal gases are sulphureted hydrogen, ammonia, and carbonic acid. A test for sulphureted hydrogen is a piece of blotting paper dipped in a solution of plumbic acetate; this is turned black on exposure to the gas. For ammonia, a strip of red litmus paper will turn blue or yellow, and a strip of yellow turmeric

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paper will turn brown, in the presence of that gas. Blue litmus paper will turn red when exposed to carbonic acid gas, and the same gas will turn limewater cloudy when passed through.

Simple Test for Drinking Water.—*Organic Matter.*—Into a perfectly clean bottle with a glass stopper, put 5 oz. of the water to be tested. Add 10 gr. of pure, granulated, white sugar. Cork tight, and set in a window exposed freely to light but not to direct rays of the sun. Do not disturb the bottle and keep the temperature as near 70° F. as possible. If the water contains organic matter, within 48 hr. an abundance of whitish specks will be seen floating about, and the more organic matter the more specks. In 1 wk. or 10 da., if the water is very bad, the odor of rancid butter will develop.

Hard Water.—All the tests necessary for ordinary practical use can be made with articles which any druggist keeps in stock. A soap solution and a few glass vials, or *test tubes*, as they are called, are needed. To ascertain whether the water is hard or soft, take a clean tube, pour about 1 in. of soap solution into it, add a few drops of water, which if hard will turn it milky or curdy.

Acidity.—To ascertain if the water is acid or alkaline, fill the tube half full of water and dip a piece of red litmus paper into it. If the paper does not turn blue the water is not alkali. Next dip a piece of blue litmus paper in it, and if the paper does not turn red the water is not acid.

Carbonic Acid.—To test for carbonic acid, pour into the tube about 1 in. of water and the same quantity of limewater. If there is carbonic acid, the water becomes milky, and on adding a little hydrochloric acid will become clear again.

Sulphate of Lime.—To see if sulphate of lime (gypsum) is present, fill the test tube with about 1½ in. of water, adding a little chloride of barium. If a white precipitate is formed, which will not dissolve when adding a little nitric acid, the water contains gypsum.

Magnesia.—A test for magnesia is made as follows: Fill a test tube ⅓ full of the water; bring it to a boil over a spirit lamp; then add a very little carbonate of ammonia, and the

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same amount of phosphate of soda; set it aside for some moments, and if magnesia is present it will form a white precipitate.

Lead.—If the test tube is ¼ full of water, and 2 drops of cochineal are added, and the water turns blue instead of pink, it will denote the presence of lead.

Copper.—Copper will be shown by adding a few drops of chloride of ammonium to some water in which has been placed a few filings of soft iron. If it turns blue, it is an evidence of copper.

Iron.—Adding 1 drop of ferrocyanide of potassium to a little water in a test tube will color it blue if iron is present.

A large number of tests are made in a thorough analysis, but these are the ones that principally interest the ordinary engineer, and can be made with the least trouble and expense. Analysts should be employed to make exact analysis of important supplies.

To Clean Galvanized-Iron Pipe.—Galvanized-iron pipe can be cleaned and polished by scouring it with fine sand or powdered pumice and water.

Polishing Lead Pipe.—Lead pipe can be cleaned and polished by scrubbing with powdered pumice and a wet cloth and then wiping dry and polishing with a dry cloth.

To preserve the polish on galvanized-iron or lead pipes, they should be immediately covered with a thin coat of white shellac or white varnish applied with a brush.

Care of Boilers in Summer.—It is considered the best practice to leave a heating system in the summer just as it has been running. Emptying the system induces rust, and if the local supply of water is hard, it induces deposits or boiler scale.

Care of Water-Closet Traps.—It frequently is necessary in cold weather to leave a closet unused in a location that cannot be warmed. To prevent the water in the trap from freezing under such conditions put into the trap about 1 lb. of common salt. This amount of salt will saturate 3 pt. of water, which is approximately the volume required to fill a closet trap, and this solution will not be frozen at any temperature above zero. Or, remove the water and fill the traps

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with oil. This is also suitable for preventing loss of seal by evaporation in unoccupied houses.

Freezing Service Pipes.—It is sometimes necessary to freeze the water in service pipes to stop the flow while making repairs. This can be accomplished by temporarily stopping the flow of water with a wooden plug and packing the pipe in one of the following freezing mixtures:

FREEZING MIXTURES.

Mixtures.	Mercury Sinks From Ordinary Temperature to	Reduction of Temperature.
2 parts of crushed ice and 1 part of salt	5° below zero	
5 parts of crushed ice, 2 parts of salt, 1 part of ammonium chloride	12° below zero	
24 parts of crushed ice, 10 parts of salt, 5 parts of ammonium chloride, 5 parts of potassium nitrate	18° below zero	
12 parts of crushed ice, 5 parts of salt, 5 parts of ammonium nitrate	25° below zero	
1 part of ammonium nitrate and 1 part of water		From 40 to 4
5 parts sodium sulphate, 4 parts of dilute sulphuric acid		From 50 to 3

Lead and Oakum.—The amount of lead and oakum required to calk different sizes of joints of cast-iron pipe may be found in the following table:

MATERIAL FOR CALKED JOINTS.

Diameter of pipe, inches	2	3	4	5	6	8	10	12
Lead per joint, pounds	1⅛	2¼	3	3⅜	4½	6	7½	9
Oakum per joint, ounces	2	6	7	8	9	11	13	18

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Disinfectants.—Deodorizers are not necessarily disinfectants, and disinfectants do not necessarily have an odor.

Water, air, and sunshine are the natural disinfectants.

Whenever a sewer is stopped up and overflows, the place where the overflow occurs should be thoroughly disinfected. This can be accomplished by sprinkling the place well with a solution of copperas, and whitewashing all walls and exposed parts of the building with a wash made of freshly slaked quicklime.

APPROXIMATE COST OF COMPLETE SYSTEMS.

Plumbing.—An approximate figure for cost of plumbing is 10 per cent. of the cost of the building. This figure is for good materials and labor, and of course is subject to considerable variation. For an ordinary house, costing from $1,500 to $3,000, the cost of plumbing may be taken as about 8 per cent. for moderate-priced fixtures and public-sewer service. The cost of labor alone will average about ¼ the cost of the materials.

Gas-Fitting.—The cost of gas-fitting may be approximately figured as about 3 per cent. of the cost of the building. The cost of labor alone varies from about ¼ to ½ the cost of materials. The better the grade of fixtures, the lower will be the ratio—provided there is no excessive ornamentation, requiring much time to put in place—as the cost of the labor is about the same for cheap fixtures as for more costly ones.

Heating.—The cost of hot-air installation is, approximately, 5 per cent. of the cost of the building; for steam heating, 8 per cent.; for hot-water heating, 10 per cent.

In estimating on heating by furnace, the average cost of labor is about ½ that of materials. In steam and hot-water heating, the ratio is about ⅛.

Caution.—The actual cost of the plumbing, gas-fitting, or heating systems in a building will vary with the price of materials, the location of the building—whether in city or country—the condition of the trade, and many other considerations. The market prices of the materials used are fluctuating all the time.

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FLUXES.

Flux.	Used With	Metals to be Joined.
Resin.	Copper bit or blowpipe.	Lead, tin, copper, brass, and tinned metals.
Tallow, unsalted.	Blowpipe or wiping process.	Lead, tin, or tinned metals.
Sal ammoniac.	Copper bit or blowpipe.	Copper, brass, and iron.
Muriatic acid.	Copper bit.	Dirty zinc.
Chloride of zinc.	Copper bit or blowpipe.	Clean zinc, copper, brass, tin, and tinned metals.
Resin and sweet oil.	Copper bit or blowpipe.	Lead and tin tubes.
Borax.	Blowpipe.	Iron, steel, copper, and brass.

IRON-PIPE SIZES OF SEAMLESS-DRAWN BRASS AND COPPER TUBES.

Size (Nominal). Inches.	Outside Diameter. Inches.	Inside Diameter. Inches.	Weight per Lineal Foot.	
			Brass. Pounds.	Copper. Pounds.
¼	⅜	.27	.30	.31
⅜	9/16	.36	.43	.45
½	11/16	.49	.58	.61
¾	13/16	.62	.80	.84
¾	1 1/16	.82	1.17	1.23
1	1 5/16	1.04	1.67	1.75
1¼	1⅝	1.38	2.42	2.54
1½	1⅞	1.61	2.92	3.07
2	2⅜	2.06	4.17	4.38
2½	2⅞	2.46	5.00	5.25
3	3½	3.06	8.00	8.40
4	4½	4.02	12.00	12.00

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LENGTH OF WIPED JOINTS FOR LEAD PIPE.

Diameter of Pipe. Inches.	Length of Joint. Inches.	Diameter of Pipe. Inches.	Length of Joint. Inches.	Diameter of Pipe. Inches.	Length of Joint. Inches.
½	2½	1¼ water	3	2 waste	2½
⅝	2¼	1¼ waste	2	2½ waste	2⅝
¾	2⅜	1½ water	3¼	3 waste	2⅝
1	2¾	1½ waste	2¼	4 waste	3

WEIGHT OF SHEET ZINC, COPPER, AND LEAD.

Zinc.		Copper.		Lead.	
Thickness. Inches.	Weight. per Sq. Ft. Ounces.	Thickness. Inches.	Weight. per Sq. Ft. Ounces.	Thickness. Inches.	Weight. per Sq. Ft. Pounds.
.031	10	.013	10	1/50	3
.046	12	.016	12	1/36	4
.053	14	.019	14	1/27	5
.061	16	.022	16	1/20	6
.069	18	.025	18	1/16	7½
.076	20	.029	20	2/15	8

WEIGHT PER FOOT OF LEAD PIPE

Tubing.		Waste Pipe.			
Diameter. Inches.	Weight. Ounces.	Diameter. Inches.	Weight. Pounds.	Diameter. Inches.	Weight. Pounds.
1/16	¾	1½	2	4	5, 6, 8
⅛	1¼	2	3, 4	4½	8, 10
3/16	2¼	2½	4, 6	5	8, 10, 12
¼	5, 6, 8, 13	3	4½, 5	6	12, up

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SOLDERS.

Variety.	Hard.			Soft.			Fusing Point.
	Zinc.	Copper.	Silver.	Tin.	Lead.	Bismuth.	
Spelter, hardest	1	2					700°
Spelter, hard	2	3					
Spelter, soft	1	1					550°
Spelter, fine	2	2	¼				
Silver, hard		1	4				
Silver, medium		1	3				
Silver, soft		1	2				
Plumbers', coarse				1	3		480°
Plumbers', ordinary				1	2		440°
Plumbers', fine				2	3		400°
Tinners'				1	1		370°
For tin pipe				3	2		330°
For tin pipe				4	4	1	

WEIGHT PER FOOT OF LEAD PIPE AND TIN-LINED LEAD PIPE.

Inside Diam.	*A A A* Brooklyn		*A A* Extra Strong.		*A* Strong.		*B* Medium.		*C* Light.		*D* Extra Light.	
In.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.
⅛	1	12	1	8	1	4	1	0	0	12	0	10
3/16							1	0	0	13		
¼	3	0	2	0	1	12	1	4	1	0	0	12
⅜	3	8	2	12	2	8	2	0	1	8	1	0
½	4	12	3	8	3	0	2	4	1	12	1	4
1	6	0	4	12	4	0	3	4	2	8	2	0
1¼	6	12	5	12	4	12	3	12	3	0	2	8
1½	8	8	7	8	6	8	5	0	4	4	3	8
1¾	10	0	8	8	7	0	6	0	5	0	4	0
2	11	12	9	0	8	0	7	0	6	0	4	12

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WEIGHT OF CAST-IRON PIPE PER FOOT IN POUNDS.

These weights are for plain pipe. For hautboy pipe add 8 in. in length for each joint. For copper add $\frac{1}{8}$; for lead, $\frac{3}{8}$; for welded iron, add $\frac{1}{16}$, or multiply by 1.0667.

Diameter of Bore. Inches.	Thickness of Pipe in Inches.									
	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜
1	3.07	5.07	7.38							
1¼	3.69	6.00	8.61							
1½	4.30	6.92	9.84							
1¾	4.92	7.84	11.10							
2	5.53	8.76	12.30	16.2						
2¼	6.15	9.69	13.50	17.7						
2½	6.76	10.60	14.80	19.2	24.0					
2¾	7.37	11.50	16.00	20.8	25.9					
3	7.98	12.50	17.20	22.3	27.7	33.4				
3½	9.21	14.30	19.70	25.4	31.4	37.7				
4	10.30	16.10	22.20	28.5	35.1	42.0				
4½	11.70	18.00	24.60	31.5	38.8	46.3				
5	12.90	19.80	27.10	34.6	42.5	50.6				
5½	14.20	21.70	29.50	37.7	46.1	54.9				
6	15.40	23.50	32.00	40.8	49.8	59.2	68.9			
6½	16.60	25.40	34.50	43.8	53.5	63.5	73.8	84.4		
7	17.80	27.20	36.90	46.9	57.2	67.8	78.7	89.4		
7½	19.10	29.10	39.40	50.0	60.9	72.1	83.7	95.5	108	
8	20.30	30.90	41.80	53.1	64.6	76.4	88.6	101.0	114	127
8½	21.50	32.80	44.30	56.1	68.3	80.7	93.5	107.0	120	134
9	22.80	34.60	46.80	59.2	72.0	85.1	98.4	112.0	126	140
9½	24.00	36.40	49.20	62.3	75.7	89.3	103.0	118.0	132	147
10	25.10	38.30	51.70	65.3	79.4	93.6	108.0	123.0	138	164
11	27.60	42.00	56.60	71.5	86.7	102.0	118.0	134.0	151	168
12	30.00	45.70	61.50	77.7	94.1	111.0	128.0	145.0	163	181
13	32.50	49.40	66.40	83.8	102.0	120.0	138.0	156.0	175	195
14	35.00	53.10	71.40	89.4	109.0	128.0	148.0	168.0	188	208
15	37.40	56.70	76.30	96.1	116.0	137.0	158.0	179.0	200	222
16	39.10	60.40	81.20	102.0	124.0	145.0	167.0	190.0	212	235
17	42.30	64.10	86.10	108.0	131.0	154.0	177.0	201.0	225	249
18	44.80	67.80	91.00	115.0	139.0	163.0	187.0	212.0	237	262
19	47.30	71.50	96.00	121.0	146.0	171.0	197.0	223.0	249	276
20	49.70	75.20	101.00	127.0	153.0	180.0	207.0	234.0	261	289
22	54.60	82.60	111.00	139.0	168.0	196.0	227.0	256.0	286	316
24	59.60	89.90	121.00	152.0	183.0	214.0	246.0	278.0	311	343
26	64.50	97.30	131.00	164.0	198.0	231.0	266.0	300.0	335	370
28	69.40	105.00	140.00	176.0	212.0	249.0	286.0	323.0	360	397
30	74.20	112.00	150.00	188.0	227.0	266.0	305.0	345.0	384	424

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WEIGHT OF SHEET IRON.

Number of Gauge.	Thickness. Inches.	Black Iron. Weight per Sq. Ft. Pounds.	Number of Gauge.	Thickness. Inches.	Black Iron. Weight per Sq. Ft. Pounds.	Galvanized Iron. Weight per Sq. Ft. Pounds.
1	.300	12.0	16	.065	2.6	3.0
2	.284	11.4	17	.058	2.3	2.7
3	.259	10.4	18	.049	2.0	2.3
4	.238	9.5	19	.042	1.7	2.1
5	.220	8.8	20	.035	1.4	1.7
6	.203	8.1	21	.032	1.3	1.5
7	.180	7.2	22	.028	1.1	1.3
8	.165	6.6	23	.025	1.0	1.2
9	.148	5.9	24	.022	0.9	1.1
10	.134	5.4	25	.020	0.8	1.0
11	.120	4.8	26	.018	0.7	1.0
12	.109	4.4	27	.016	0.6	0.9
13	.095	3.8	28	.014	0.6	0.7
14	.083	3.3	29	.013	0.5	0.7
15	.072	2.9	30	.012	0.5	0.6

SPACING OF LEAD-PIPE TACKS.

Size of Pipe. Inches.	Vertical Pipe.		Horizontal Pipe.	
	Hot. Inches.	Cold. Inches.	Hot. Inches.	Cold. Inches.
¼	18	24	12	16
⅜	19	25	14	17
½	20	26	15	18
¾	21	27	16	19
1	22	28	17	20
1¼	23	29	18	21
1½	24	30	18	22

Tacks are spaced closer on hot than on cold pipes, as lead is much more liable to sag when heated.

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EXPANSION AND WEIGHT OF PURE WATER FROM 32° TO 390° F.

Temperature. Degrees Fahrenheit.	Comparative Volume. Water at 32° = 1.	Comparative Density. Water at 32° = 1.	Weight of 1 Cu. Ft. Pounds.	Temperature. Degrees Fahrenheit.	Comparative Volume. Water at 32° = 1.	Comparative Density. Water at 32° = 1.	Weight of 1 Cu. Ft. Pounds.
32.0	1.00000	1.00000	62.418	135.0	1.01539	.98484	61.472
35.0	.99993	1.00007	62.422	140.0	1.01690	.98339	61.381
39.1	.99989	1.00011	62.425	145.0	1.01839	.98194	61.291
40.0	.99989	1.00011	62.425	150.0	1.01989	.98050	61.201
45.0	.99993	1.00007	62.422	155.0	1.02164	.97882	61.096
46.0	1.00000	1.00000	62.418	160.0	1.02340	.97714	60.991
50.0	1.00015	.99985	62.409	165.0	1.02589	.97477	60.843
52.3	1.00029	.99971	62.400	170.0	1.02690	.97380	60.783
55.0	1.00038	.99961	62.394	175.0	1.02906	.97193	60.665
60.0	1.00074	.99926	62.372	180.0	1.03100	.97006	60.548
62.0	1.00101	.99899	62.355	185.0	1.03300	.96828	60.430
65.0	1.00119	.99881	62.344	190.0	1.03500	.96632	60.314
70.0	1.00160	.99832	62.313	195.0	1.03700	.96440	60.198
75.0	1.00239	.99771	62.275	200.0	1.03889	.96256	60.081
80.0	1.00299	.99702	62.240	205.0	1.04140	.96020	59.930
85.0	1.00379	.99622	62.182	210.0	1.04340	.95840	59.820
90.0	1.00459	.99543	62.133	212.0	1.04440	.95750	59.760
95.0	1.00554	.99449	62.074	230.0	1.05290	.94990	59.360
100.0	1.00639	.99365	62.022	250.0	1.06280	.94110	58.750
105.0	1.00739	.99260	61.960	270.0	1.07270	.93230	58.180
110.0	1.00889	.99119	61.868	290.0	1.08380	.92270	57.590
115.0	1.00989	.99021	61.807	298.0	1.08990	.91750	57.270
120.0	1.01139	.98874	61.715	338.0	1.11180	.89940	56.140
125.0	1.01239	.98808	61.654	366.0	1.13010	.88500	55.290
130.0	1.01390	.98630	61.563	390.0	1.14440	.87380	54.540

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BUSINESS LAWS IN DAILY USE.

The following compilation of business law contains the essence of a large amount of legal verbiage:

If a note is lost or stolen, it does not release the maker; he must pay it, if the consideration for which it was given and the amount can be proved.

Notes bear interest only when so stated.

Principals are reponsible for the acts of their agents.

Each individual in a partnership is responsible for the whole amount of the debts of the firm, except in cases of special partnership.

Ignorance of the law excuses no one.

The law compels no one to do impossibilities.

An agreement without consideration is void.

A note made on Sunday is void.

Contracts made on Sunday cannot be enforced.

A note by a minor is voidable. A contract made with a minor is void.

A contract made with a lunatic is void.

A note obtained by fraud, or from a person in a state of intoxication, cannot be collected.

It is a fraud to conceal a fraud.

Signatures made with a lead pencil are good in law.

A receipt for money is not always conclusive.

The acts of one partner bind all the rest.

"Value received" is usually written in a note, and should be, but it is not necessary. If not written, it is presumed by law, or may be supplied by proof.

The maker of an "accommodation" bill or note (one for which he has received consideration, having lent his name on credit for the accommodation of the holder) is not bound to the person accommodated, but is bound to all other parties, precisely as if there were a good consideration.

No consideration is sufficient in law if it be illegal in its nature.

Checks or drafts must be presented for payment without unreasonable delay.

Checks or drafts should be presented during busines-

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hours; but in this country, except in the case of banks, the time extends through the day and evening.

If the drawee of a check or draft has changed his residence the holder must use due or reasonable diligence to find him.

If one who holds a check, as payee or otherwise, transfers it to another, he has a right to insist that the check be presented that day, or at farthest, on the following day.

A note indorsed in blank (the name of the indorser only written) is transferable by delivery, the same as if made payable to the bearer.

If time of payment of a note is not named, it is payable on demand.

The time of payment of a note must not depend on a contingency. The promise must be absolute.

A bill may be written on any kind of paper, either with ink or pencil.

The payee should be named in the note, unless it is payable to bearer.

An indorser has a right of action against all whose names were on the bill when he received it.

If the letter containing a protest of non-payment be put into the post office, its miscarriage does not affect the party giving notice; notice of protest may be sent either to the place of business or of residence of the party notified.

The holder of a note may give notice of protest either to all the previous indorsers or only to one of them; in the latter case, he must select the last indorser, and the last must give notice to the last before him, and so on. Each indorser must send notice the same day or the day following. Neither Sunday nor any legal holiday is counted in reckoning time in which notice is to be given.

The loss of a note is not sufficient excuse for not giving notice of protest.

If two or more persons, as partners, are jointly liable on a note or bill, due notice to one of them is sufficient.

If a note or a bill is transferred as security, or even as payment of a preexisting debt, the debt revives if the note or bill be dishonored.

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An indorsement may be written on the face or back.

An indorser may prevent his own liability to be sued by writing "without recourse" or similar words.

An oral agreement must be proved by evidence. A written agreement proves itself The law prefers written to oral evidence, because of its precision

No evidence can be introduced to contradict or vary a written contract; but it may be received in order to explain it, when such explanation is needed.

Written instruments are to be construed and interpreted by the law according to the simple customary and natural meaning of the words used.

The finder of negotiable paper, as of all other property, must make reasonable efforts to find the owner before he is entitled to appropriate it for his own purposes. If the finder conceals it, he is liable to the charge of larceny or theft.

Joint payees of a bill or note that are not partners must all join in an indorsement.

One may make a note payable to his own order and indorse it in blank. He must write his name across its back or face, the same as any other indorser.

After the death of a holder of a bill or note, his executor or administrator may transfer it by his indorsement.

The husband that acquires a right to a bill or note that was given to the wife, either before or after marriage, may indorse it.

Acceptance applies to bills and not to notes. It is an engagement on the part of the person on whom the bill is drawn to pay it according to its tenor. The usual way is to write across the face of the bill the word "accepted."

TABLE OF WAGES.

The following tables show the amount of wages to be paid per day or week at 8, 9, and 10 hr. per da. at from 50 ct. to $5 a da., and from $3 to $27 a wk. The manner of using the tables is so simple that an explanation seems unnecessary. All who figure wages will find these tables of great help and savers of valuable time and labor.

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TABLE OF WAGES

Ten-Hour Day

Per Day	0.50	0.60	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00
½ hour	.03	.03	.04	.05	.06	.08	.09	.10	.11	.13	.14	.15	.16	.18	.19	.20	.21	.23	.24	.25
1 hour	.05	.06	.08	.10	.13	.15	.18	.20	.23	.25	.28	.30	.33	.35	.38	.40	.43	.45	.48	.50
2 hours	.10	.12	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.00
3 hours	.15	.18	.23	.30	.38	.45	.53	.60	.68	.75	.83	.90	.98	1.05	1.13	1.20	1.28	1.35	1.43	1.50
4 hours	.20	.24	.30	.40	.50	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
5 hours	.25	.30	.38	.50	.63	.75	.88	1.00	1.13	1.25	1.38	1.50	1.63	1.75	1.88	2.00	2.13	2.25	2.38	2.50
6 hours	.30	.36	.45	.60	.75	.90	1.05	1.20	1.35	1.50	1.65	1.80	1.95	2.10	2.25	2.40	2.55	2.70	2.85	3.00
7 hours	.35	.42	.53	.70	.88	1.05	1.23	1.40	1.58	1.75	1.93	2.10	2.28	2.45	2.63	2.80	2.98	3.15	3.33	3.50
8 hours	.40	.48	.60	.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00
9 hours	.45	.54	.68	.90	1.13	1.35	1.58	1.80	2.03	2.25	2.48	2.70	2.93	3.15	3.38	3.60	3.83	4.05	4.28	4.50
10 hours	.50	.60	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00

Nine-Hour Day

½ hour	.03	.03	.04	.06	.07	.08	.10	.11	.13	.14	.15	.17	.18	.19	.21	.22	.24	.25	.26	.28
1 hour	.06	.07	.08	.11	.14	.17	.20	.22	.25	.28	.31	.33	.36	.39	.42	.45	.47	.50	.53	.56
2 hours	.11	.13	.17	.22	.28	.33	.39	.44	.50	.56	.61	.67	.72	.78	.83	.89	.94	1.00	1.06	1.11
3 hours	.17	.20	.25	.33	.42	.50	.58	.67	.75	.83	.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67
4 hours	.22	.27	.33	.44	.56	.67	.78	.89	1.00	1.11	1.22	1.33	1.44	1.56	1.67	1.78	1.89	2.00	2.11	2.22
5 hours	.28	.33	.42	.56	.69	.83	.97	1.10	1.25	1.39	1.53	1.67	1.81	1.94	2.08	2.22	2.36	2.50	2.64	2.78
6 hours	.33	.40	.50	.67	.83	1.00	1.17	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50	2.67	2.83	3.00	3.17	3.33
7 hours	.39	.47	.58	.78	.97	1.17	1.36	1.56	1.75	1.94	2.14	2.33	2.53	2.72	2.92	3.11	3.31	3.50	3.69	3.89
8 hours	.44	.53	.67	.89	1.11	1.33	1.56	1.78	2.00	2.22	2.44	2.67	2.89	3.11	3.33	3.56	3.78	4.00	4.22	4.44
9 hours	.50	.60	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00

Eight-Hour Day

½ hour	.03	.04	.05	.06	.08	.10	.11	.13	.14	.16	.17	.19	.20	.22	.23	.25	.26	.28	.29	.31
1 hour	.06	.08	.09	.13	.16	.19	.22	.25	.28	.31	.34	.38	.41	.44	.47	.50	.53	.56	.59	.63
2 hours	.13	.15	.19	.25	.31	.38	.44	.50	.56	.63	.69	.75	.81	.88	.94	1.00	1.07	1.13	1.19	1.25
3 hours	.19	.23	.28	.38	.47	.56	.66	.75	.84	.94	1.03	1.13	1.22	1.31	1.40	1.50	1.59	1.69	1.79	1.88
4 hours	.25	.30	.38	.50	.63	.75	.88	1.00	1.13	1.25	1.38	1.50	1.63	1.75	1.88	2.00	2.13	2.25	2.38	2.50
5 hours	.31	.38	.47	.63	.78	.94	1.09	1.25	1.41	1.56	1.72	1.88	2.03	2.19	2.34	2.50	2.65	2.81	2.97	3.13
6 hours	.38	.45	.56	.75	.94	1.13	1.31	1.50	1.69	1.88	2.06	2.25	2.44	2.63	2.82	3.00	3.19	3.38	3.57	3.75
7 hours	.44	.53	.66	.88	1.09	1.31	1.53	1.75	1.97	2.19	2.41	2.63	2.84	3.06	3.28	3.50	3.72	3.94	4.16	4.38
8 hours	.50	.60	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00

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TABLE OF WAGES

Per Week of Six Days	3.00	3.50	4.00	4.50	5.00	7.00	7.50	8.00	9.00
1 day	.50	.58	.67	.75	.83	1.17	1.25	1.33	1.50
2 days	1.00	1.17	1.33	1.50	1.67	2.33	2.50	2.67	3.00
3 days	1.50	1.75	2.00	2.25	2.50	3.50	3.75	4.00	4.50
4 days	2.00	2.33	2.67	3.00	3.33	4.67	5.00	5.33	6.00
5 days	2.50	2.92	3.33	3.75	4.17	5.83	6.25	6.67	7.50
6 days	3.00	3.50	4.00	4.50	5.00	7.00	7.50	8.00	9.00
7 days	3.50	4.08	4.67	5.25	5.83	8.17	8.75	9.33	10.50
8 days	4.00	4.67	5.33	6.00	6.67	9.33	10.00	10.67	12.00
9 days	4.50	5.25	6.00	6.75	7.50	10.50	11.25	12.00	13.50
10 days	5.00	5.83	6.67	7.50	8.33	11.67	12.50	13.33	15.00
11 days	5.50	6.42	7.33	8.25	9.17	12.83	13.75	14.67	16.50
12 days	6.00	7.00	8.00	9.00	10.00	14.00	15.00	16.00	18.00
13 days	6.50	7.58	8.67	9.75	10.83	15.17	16.25	17.33	19.50
14 days	7.00	8.17	9.33	10.50	11.67	16.33	17.50	18.67	21.00
15 days	7.50	8.75	10.00	11.25	12.50	17.50	18.75	20.00	22.50
16 days	8.00	9.33	10.67	12.00	13.33	18.67	20.00	21.33	24.00
17 days	8.50	9.92	11.33	12.75	14.17	19.83	21.25	22.67	25.50
18 days	9.00	10.50	12.00	13.50	15.00	21.00	22.50	24.00	27.00
19 days	9.50	11.08	12.67	14.25	15.83	22.17	23.75	25.33	28.50
20 days	10.00	11.67	13.33	15.00	16.67	23.33	25.00	26.67	30.00
21 days	10.50	12.25	14.00	15.75	17.50	24.50	26.25	28.00	31.50
22 days	11.00	12.83	14.67	16.50	18.33	25.67	27.50	29.33	33.00
23 days	11.50	13.42	15.33	17.25	19.17	26.83	28.75	30.67	34.50
24 days	12.00	14.00	16.00	18.00	20.00	28.00	30.00	32.00	36.00
25 days	12.50	14.58	16.67	18.75	20.83	29.17	31.25	33.33	37.50
26 days	13.00	15.17	17.33	19.50	21.67	30.33	32.50	34.67	39.00
27 days	13.50	15.75	18.00	20.25	22.50	31.50	33.75	36.00	40.50
28 days	14.00	16.33	18.67	21.00	23.33	32.67	35.00	37.33	42.00
29 days	14.50	16.92	19.33	21.75	24.17	33.83	36.25	38.67	43.50
30 days	15.00	17.50	20.00	22.50	25.00	35.00	37.50	40.00	45.00
31 days	15.50	18.08	20.67	23.25	25.83	36.17	38.75	41.33	46.50
Per Day at Seven Days Per Week	.43	.50	.59	.64	.71	1.00	1.07	1.14	1.29

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TABLE.—(*Continued.*)

Per Week of Six Days	10.50	13.50	15.00	16.50	19.50	21.00	22.50	27.00
1 day	1.75	2.25	2.50	2.75	3.25	3.50	3.75	4.50
2 days	3.50	4.50	5.00	5.50	6.50	7.00	7.50	9.00
3 days	5.25	6.75	7.50	8.25	9.75	10.50	11.25	13.50
4 days	7.00	9.00	10.00	11.00	13.00	14.00	15.00	18.00
5 days	8.75	11.25	12.50	13.75	16.25	17.50	18.75	22.50
6 days	10.50	13.50	15.00	16.50	19.50	21.00	22.50	27.00
7 days	12.25	15.75	17.50	18.75	22.75	24.50	26.25	31.50
8 days	14.00	18.00	20.00	22.00	26.00	28.00	30.00	36.00
9 days	15.75	20.25	22.50	24.75	29.25	31.50	33.75	40.50
10 days	17.50	22.50	25.00	27.50	32.50	35.00	37.50	45.00
11 days	19.25	24.75	27.50	30.25	35.75	38.50	41.25	49.50
12 days	21.00	27.00	30.00	33.00	39.00	42.00	45.00	54.00
13 days	22.75	29.25	32.50	35.75	42.25	45.50	48.75	58.50
14 days	24.50	31.50	35.00	38.50	45.50	49.00	52.50	63.00
15 days	26.25	33.75	37.50	41.25	48.75	52.50	56.25	67.50
16 days	28.00	36.00	40.00	44.00	52.00	56.00	60.00	72.00
17 days	29.75	38.25	42.50	46.75	55.25	59.50	63.75	76.50
18 days	31.50	40.50	45.00	49.50	58.50	63.00	67.50	81.00
19 days	33.25	42.75	47.50	52.25	61.75	66.50	71.25	85.50
20 days	35.00	45.00	50.00	55.00	65.00	70.00	75.00	90.00
21 days	36.75	47.25	52.50	57.75	68.25	73.50	78.75	94.50
22 days	38.50	49.50	55.00	60.50	71.50	77.00	82.50	99.00
23 days	40.25	51.75	57.50	63.25	74.75	80.50	86.25	103.50
24 days	42.00	54.00	60.00	66.00	78.00	84.00	90.00	108.00
25 days	43.75	56.25	62.50	68.75	81.25	87.50	93.75	112.50
26 days	45.50	58.50	65.00	71.50	84.50	91.00	97.50	117.00
27 days	47.25	60.75	67.50	74.25	87.75	94.50	101.25	121.50
28 days	49.00	63.00	70.00	77.00	91.00	98.00	105.00	126.00
29 days	50.75	65.25	72.50	79.75	94.25	101.50	108.75	130.50
30 days	52.50	67.50	75.00	82.50	97.50	105.00	112.50	135.00
31 days	54.25	69.75	77.50	85.25	100.75	108.50	116.25	139.50
Per Day at Seven Days Per Week	1.50	1.93	2.14	2.36	2.79	3.00	3.21	3.86

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AUTOMATIC SPRINKLER SYSTEMS.

Automatic sprinkler systems that are designed to afford protection against the destruction of property by fire, consist of a number of sprinkler heads attached to a system of iron pipes that supply the sprinklers with water under pressure from a tank located on the roof of the building, or by water under pressure from the street mains, or pneumatic supply tank in the basement.

In operation, the sprinklers throw out a heavy spray of water when the flames melt a fusible part of the sprinkler head, whereupon a valve flies open and the water flows out.

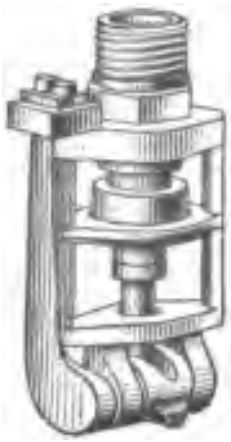

FIG. 1.

FIG. 2.

Although there are many kinds of sprinklers on the market they all operate in a similar manner. Fig. 1 shows a sprinkler closed and ready for action; Fig. 2 shows it open after the fusible link has been melted apart. The valve in this sprinkler is held to its seat by a bell-crank secured at its upper end by fusible links. The solder used in joining the links is an alloy having a very low melting point. The heat of a fire melts the links. The water pressure forces the valves open and extinguishes the fire.

In places where corrosive fumes abound, such for example as bleacheries, paper mills, tanneries, match works, chemical

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works, etc., the sprinklers should be protected from corrosion by a coating of specially prepared wax that melts at about 160° F., which is a few degrees below the fusing point of the soft solder used in closing sprinklers. Under ordinary circumstances a sprinkler should open and throw a stream when the temperature of the soldered parts reaches 165° F.; but for boiler and engine rooms, dry rooms, and such places, high-test sprinklers are used.

There are four grades of solder in common use; one fuses at 165°, another at 212°, another at 280°, and another at 360°.

Very large sprinklers are used in elevator shafts, light wells, and other such places where a large quantity of water would be required in case of fire. The nozzles of these sprinklers should be at least 1½ in. in diameter.

Automatic sprinkler systems should be provided with two sources of water supply, one of which should constantly bear on the sprinklers; the other one, preferably from an approved

DISTANCE BETWEEN SPRINKLERS FOR STANDARD MILL CONSTRUCTION.

ONE ROW OF AUTOMATIC SPRINKLERS IN EACH BAY PLACED MIDWAY BETWEEN BEAMS.

	With Water Pressure at Highest Sprinkler			
	Exceeding 20 Lb. per Sq. In.		Less Than 20 Lb. per Sq. In. or Supplied Primarily by Tank.	
	Medium Hazard.	Special Hazard.	Medium Hazard.	Special Hazard.
In 12-ft. bays	8 ft. apart	7 ft. apart	7 ft. apart	6 ft. apart
In 11-ft. bays	9 ft. apart	8 ft. apart	8 ft. apart	7 ft. apart
In 10-ft. bays	10 ft. apart	9 ft. apart	9 ft. apart	8 ft. apart
In 9-ft. bays	11 ft. apart	10 ft. apart	10 ft. apart	9 ft. apart
In 8-ft. bays	12 ft. apart	11 ft. apart	11 ft. apart	10 ft. apart
In 7-ft. bays	12 ft. apart	11 ft. apart	11 ft. apart	10 ft. apart

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fire-pump, should be used automatically as an auxiliary supply. Check-valves placed on the main supply pipes from the two sources and opening toward the sprinklers will permit water to flow to the sprinklers from whichever source of supply has the greater pressure. This avoids the undesirable necessity of manipulating valves in case of fire.

The accompanying tables of the Factory Mutual Insurance Companies give the proper distance between sprinklers.

DISTANCE BETWEEN SPRINKLERS FOR OPEN-JOISTED CEILINGS.

SPRINKLERS SHOULD PREFERABLY BE PLACED DIRECTLY UNDER A JOIST.

	With Water Pressure at Highest Sprinkler			
	Exceeding 20 Lb. per Sq. In.		Less Than 20 Lb. per Sq. In. or Supplied Primarily by Tank.	
	Medium Hazard.	Special Hazard.	Medium Hazard.	Special Hazard.
At right angle to joists	8 ft. apart	7½ ft. apart	7½ ft. apart	6½ ft. apart
Parallel with joists	10 ft. apart	9 ft. apart	9 ft. apart	8 ft. apart

The terms *medium hazard* and *special hazard* relate to the contents and character of each room. Especially hazardous places are such as planing or sawing departments of wood-working mills, painting and varnishing rooms, etc.

In all cases the distance from walls to nearest sprinklers should not exceed one-half the distance between the sprinklers in the same direction.

Fig. 3 shows a combined street-pressure and tank-pressure system of piping installed in a large mill. A check-valve is

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placed on the large main underneath the hall of the stairway, to prevent tank water from going back to the main should the pressure therein be reduced at any time, and there is a check-valve on the large supply line in the room under the tank, to prevent the street water from rising and overflowing the tank. The tank may be filled and kept full by means of an ordinary ball-cock, supplied by a small branch pipe from the street-service pipe. In combination with the stand pipe is an automatic alarm attachment that operates a gong when

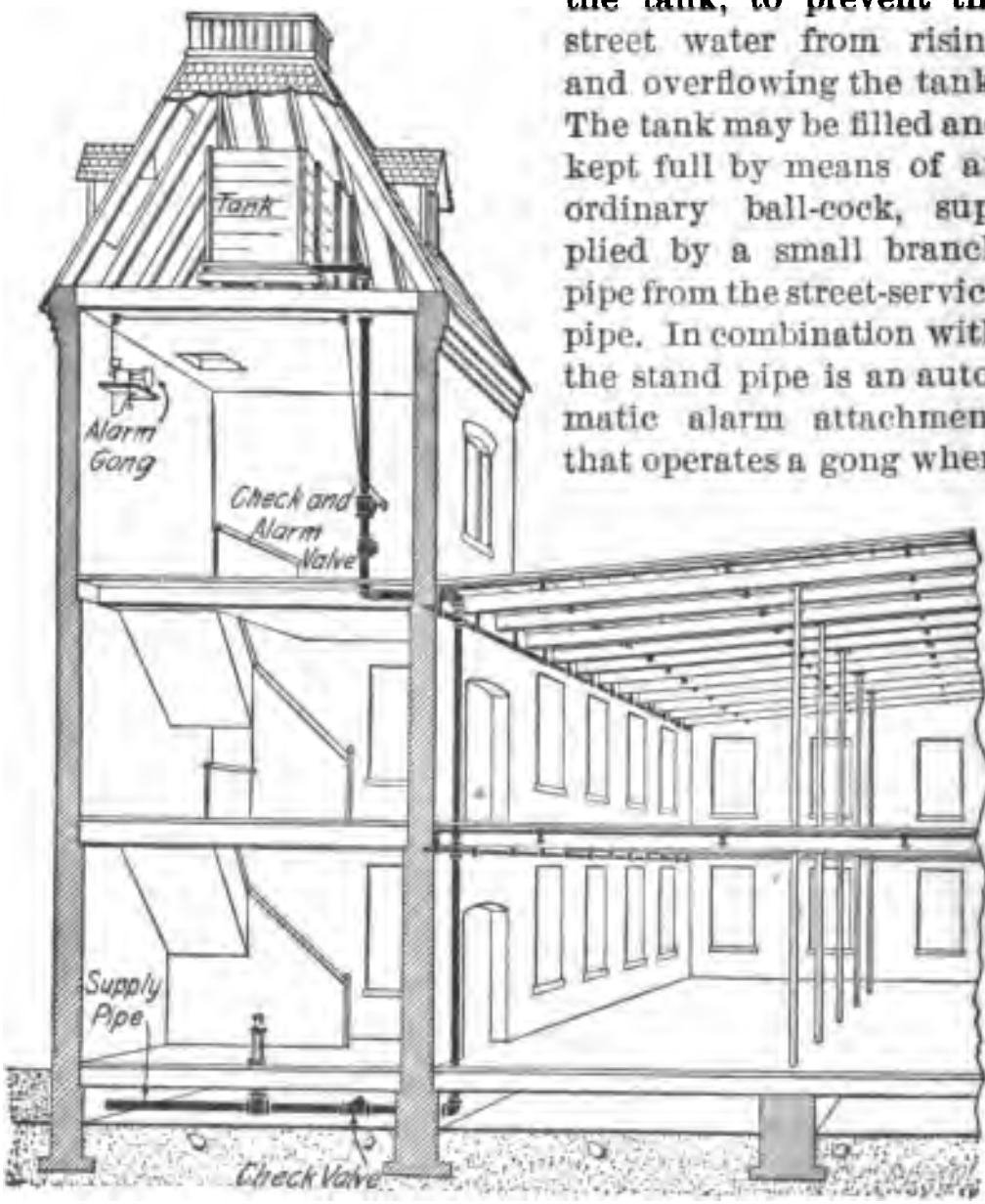

FIG. 3.

the water begins to flow to the sprinklers, which are shown arranged along the ceiling. The system shown is called a *wet system* because the water pressure is always on the sprinklers.

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The *dry pipe system* is one in which water is turned on the main pipes that supply the pipes in the building, but an air pressure greater than the water pressure is maintained in the distributing pipes. When a sprinkler is open the air in the pipe system immediately begins to escape. The air pressure is thus lowered and water automatically flows into the system and escapes through the open sprinklers. The dry system is desirable only in places where wet pipes will freeze.

The general Underwriters' requirements for proper installation of sprinkler systems call for the use of two independent water supplies, in order to secure the minimum rate of insurance, which may be from 30 to 50 per cent. reduction on the total insurance rates. One of these supplies must be automatic, and one should furnish water under heavy pressure.

The Underwriters accept the following combinations: Public waterworks and duplex steam pump; public waterworks and air-pressure tanks; elevated gravity tank and duplex steam pump; public waterworks and elevated gravity tank; public waterworks and rotary pump; elevated gravity tank and air-pressure tank; elevated gravity tank and rotary pumps.

In most of the foregoing combinations it might be possible to substitute the air-pressure tank in lieu of the gravity tank. The choice of these supplies is determined by the Underwriters.

A steam pressure of not less than 50 lb. should be maintained at all times on the pump, and an automatic regulator should be applied to the steam pump, so that it will start automatically when a sprinkler is unsealed, furnishing the system with a full supply of water.

Fire-pumps built according to the Underwriters' pump specifications of the Associated Factory Mutual Insurance Companies, dated May 20, 1893, have given the best satisfaction and are recommended.

The 500-gal. pump, which is $10 \times 7 \times 12$ (ordinary size for small mills), has 8″ suction, 6″ discharge, 3″ steam, 4″ exhaust, and 2″ hose outlets.

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The 750-gal. pump, which is 16 × 9 × 12 (ordinary size for general use), has 10″ suction, 7″ discharge, 3½″ steam, 4″ exhaust, and 3″ hose outlets.

The 1,000-gal. pump, 18 × 10 × 12 (usual size for large factories), has 12″ suction, 8″ discharge, 4″ steam, 5″ exhaust, and 4″ hose outlets.

A water gauge and a pressure gauge should be connected to the end of the tank, with try cocks and blow-off drips. Air-pressure tanks should be constructed according to the Underwriters' rules, and their capacities determined by the Underwriters. These tanks should be located in the upper story of the building and must be kept ⅔ full of water,

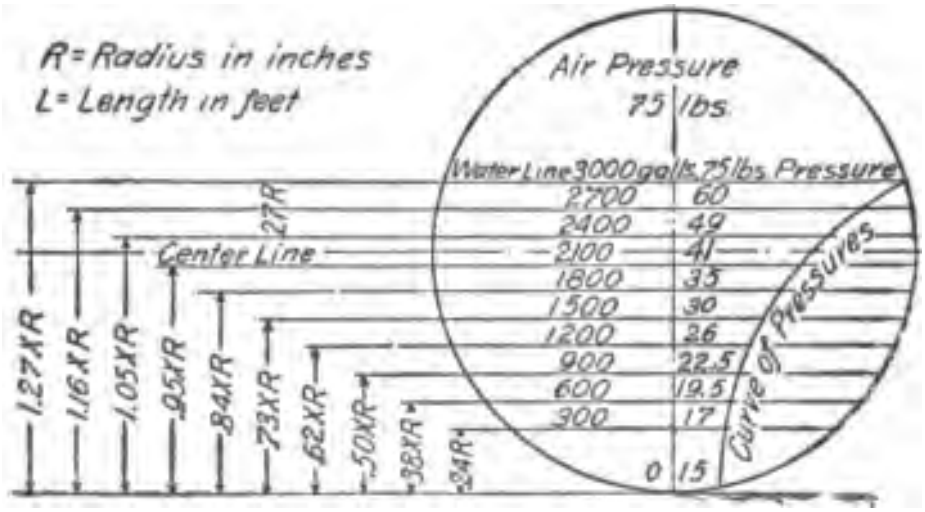

FIG. 4.

and an air pressure maintained (never less than 75 lb.) that will give not less than 15 lb. pressure on the highest line of sprinklers when all water has been discharged from the tank.

Fig. 4 shows the pressures and quantities of water in pressure tanks at different water levels.

The sizes of pipes for a sprinkler system will in all cases be determined by the Underwriters having jurisdiction. In December, 1896, at a meeting of the Underwriters, held in New York City, a committee was appointed to deal with the subject of automatic sprinkler installations and establish uniform rules for same. The result of their work is indicated in the third and fourth columns of the following table:

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NUMBER OF SPRINKLERS ALLOWED ON A GIVEN SIZE OF PIPE.

Size of Pipe.	Number of Sprinklers Allowed.		
	Main Pipes.		Branch Pipes.
	Associated Factory Mutual Insurance Companies.	National Board of Fire Underwriters.	National Board of Fire Underwriters.
¾	1	1	1
1	2	2	2
1¼	3	4	4
1½	5	8	6
2	10	16	8
2½	20	28	16
3	36	48	28
3½	55	78	
4	80	110	
4½	110		
5	140	150	
6	200	200	

For branch lines on which there are more than 6 sprinklers the above pipe schedule shall, after passing the sixth sprinkler, apply to the next larger size of piping.

When the sprinklers required on any single floor exceed the number allowed to a 6″ pipe, then a number of supply pipes are used, either 4″, 5″, or 6″ pipes.

The Underwriters' schedules must be strictly adhered to by the constructing engineer, except where special permission is granted by the Underwriters to make changes. The size of the risers is determined by the number of sprinklers required on each floor of the building or in any section divided by fire walls. Belt, stair, or elevator towers should be treated as one room, and the pipe sizes arranged accordingly. In no case should risers or supply pipes for sprinkler systems be tapped for domestic purposes.

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Promotion Advancement in Salary and Business Success

Secured
Through the

PLUMBING, HEATING and VENTILATION

COURSES OF INSTRUCTION

OF THE

International Correspondence Schools

International Textbook
Company, Proprietors

SCRANTON, PA., U. S. A.

SEE FOLLOWING PAGES

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Special Ability Insures Success

The technical information gained in my study of your Complete Plumbing and Heating Course has been of great benefit to me. Through it I was enabled to obtain and hold a position as foreman in the largest shop in this city, doing tinsmithing, plumbing, and furnace work. I am now senior partner in a plumbing, heating, and electrical establishment, employing 35 men. During the last year we have put through all the largest jobs of work in our line in this city. The I. C. S. system of training is of such value that no workman who desires to be progressive or keep abreast of the times can afford to do without it.

E. J. YOUNG,
Box 215, Calgary, N. W. T., Can.

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STARTED PLUMBING SHOP

MAX L. FRAKER, Shelbyville, Ill., was a fireman and engineer in a power plant when he started to study the I. C. S. Course in Plumbing and Heating. As a result of the Course, Mr. Fraker has started a plumbing and heating shop of his own, running it successfully for the past three years.

I. C. S. STUDENT BECOMES INVENTOR

JAMES LONG, 2229 17th Avenue, South, Minneapolis, Minn., a student of the Sanitary Plumbing, Heating, and Ventilation Course, has designed and patented a steam appliance. He attributes to his Course in the I. C. S. credit for giving him the knowledge necessary to his success. Mr. Long has risen from journeyman steam fitter to a lucrative business of his own as contractor in plumbing and heating. He now is manager of such a firm.

A SUBSTANTIAL SALARY INCREASE IN ONE YEAR

CHRISTOPHER GROSS, 99 Oak St., Wyandotte, Mich., says: "I simply cannot keep out of work since taking up a Course with the Schools." Mr. Gross has not yet finished his Course, but he is studying. He is a steam fitter, employed by the American Ship Building Company at present. After studying less than a year the knowledge gained increased his salary from $2.50 to $3 a day.

IN BUSINESS FOR HIMSELF

J. C. PATMORE, Morrissey Mines, B. C., was a tinsmith when he enrolled in the Complete Plumbing and Heating Course. His earnings were $2 a day. As a result of his studies he is able to conduct a business of his own in which the profits from his labor are much greater than when he was working for some one else.

NOW IS PARTNER IN A BUSINESS

DAVID C. BUERGER, 21-23 Grand St., Albany, N. Y., holds the I. C. S. Diploma from the School of Heating. When he started the Course he was a steam and gas-fitter. Since he finished it he designs and superintends the installation of heating systems and is partner in a paying gas-fitting business.

HELPER TO PLUMBER

THOMAS W. CAREY, 1256 Tuendawie St., Defiance, Ohio, a plumber, was a plumber's helper, at half his present wages, when he first started to study the Complete Plumbing and Heating Course.

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Doubled His Income

I am glad to inform you that the Board of Directors has seen fit to accept my application and elect me superintendent of the Boonville Water Company, and I wish to say that it was through the knowledge obtained in my Course that I won the confidence of this company, which represents a capital stock of $100,000. I feel that had it not been for the Schools I would not have been in this position today, for when I enrolled I was working in a plumbing shop. My income now is just double what it was when I began. The I. C. S. Courses are the best opportunities open to young people to advance in their positions.

JAS. H. LIEBER,
Boonville, Mo.

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WAGES INCREASED 60 PER CENT.

FRED SCHAUPP, 322 Guerrero St., San Francisco, Cal., enrolled in the Complete Plumbing Course, studied, and is now making 60 per cent. more than before. His future is bright.

AN I. C. S. EDUCATION PAYS

PETER D. BUTLER, East Hampton, N. Y., found that it pays him to have the knowledge he received from his I. C. S. Course. When he enrolled he was an apprentice: he now is a journeyman plumber, making four times his previous wages.

THE GREATEST THING EVER

EGBERT C. DOUGHTY, Hackensack, N. J., says that for the mechanic, I. C. S. instruction is the greatest thing that ever happened—that he would not take $5,000 for the knowledge gained from his Course. When Mr. Doughty enrolled he was a plumber making $3 a day. He now is in business for himself, has a much larger income, and unlimited good prospects.

HIS AMBITION REALIZED

L. A. MCGUIGAN, Davis, W. Va., was an apprentice when he enrolled for the Complete Heating Course. Before his apprenticeship term expired he secured, because of his studies, a much better position with a firm in the heating business. He went on earning more and more money until at present he has a business of his own that pays well.

HELPER BECOMES JOURNEYMAN PLUMBER

PAUL K. BECKMAN, 1123 Pine St., Seattle, Wash., took a Course in the I. C. S. while helper in a plumber's shop. He studied the up-to-date methods taught in his Course with the result that he is now a full-fledged journeyman plumber. By means of the Reference Library Volumes furnished with his Course he can do lots of work that he knew nothing about before using the Volumes.

SALARY INCREASED 25 PER CENT.

E. S. BEARDSLEY, Rutland, Vt., says the I. C. S. system is one of the finest systems in existence for helping those compelled to work for a living. When he enrolled he was a plumber and steam fitter: the result of his studies is an increase in salary of 25 per cent.

BECAME A BUSINESS SUCCESS

E. L. COLE, Sunfield, Mich., as a result of his studies in the I. C. S. School of Plumbing, has graduated from journeyman to a hardware, plumbing, and heating business of his own.

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Journeyman Plumber Becomes City Inspector

I take this opportunity to let you know what your School has done for me.

When I enrolled for your Complete Plumbing and Heating Course, I was working as a journeyman plumber. On January 1, 1903, I was appointed Plumbing Inspector for this city, which position I still fill. I can safely say that my success in filling the position is due to the training I received through your valuable system of instruction by mail. My advancement brings increased pay and much better working conditions.

Further, I may say that I always urge my friends to enroll with you, for I know if your instructions as to study, etc. are followed, success awaits them.

Thanking you for past favors,

M. M. O'CONNELL,
Plumbing Inspector,
City Hall, Ottawa.

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ANOTHER BUSINESS SUCCESS

LEO KOB, Elizabethtown, Pa., was trying to learn the plumbing trade when he decided to let the I. C. S. help him. From $3 a week to an independent plumbing and tinning business is Mr. Kob's record. The Course helps him do accurate work in laying out jobs and teaches him how to do it intelligently.

SALARY DOUBLED IN TWO MONTHS

D. L. STYLES, Gobleville, Mich., started the Plumbing and Heating Course while working for $6 a week. In less than 2 months he was able to accept a position that paid $12 a week. In this position he received increases. He now is in business for himself, making a specialty of plumbing and heating. He says: "I would not part with what I learned from the I. C. S. for one hundred times what it cost me."

FROM $7 A WEEK TO A SUCCESSFUL BUSINESS

W. E. O'BRIEN, 427 Williams St., Jackson, Mich., enrolled in the Sheet-Metal Pattern Drafting Course while making $7 a week. After progressing a little in his studies his wages were increased to $10 a week. Then he applied for a position with the Smith Company, of Jackson, and received it, with wages at $15 a week. After working in this position a short time he was taken into partnership with the firm of Beals, O'Brien & Co., where he still is. Mr. O'Brien, in a letter to the Schools, writes: "Your Course of Instruction has enabled me to cope with any problem in pattern cutting that I have yet encountered. When I enrolled I did not know the rudiments of pattern drafting but can now say that it would be a pretty deep problem I could not solve."

A UNIVERSITY MAN BENEFITED

FRED D. ROLLINS, 710 Seventh Ave., So. E., Minneapolis, Minn., after leaving the University of Minnesota, enrolled for the I. C. S. Sanitary Plumbing, Heating, and Ventilation Course and has steadily risen on the salary ladder. Mr. Rollins says: "I think, all things taken into consideration, my Course will net me more than any college education, and I say this with a full appreciation of what a college education means."

WAGES INCREASED 50 PER CENT.

JAMES A. BLACKNEY, Ishpeming, Mich., a student in the I. C. S. School of Plumbing, has advanced from journeyman to foreman in the plumbing business. His wages have been increased 50 per cent. since enrolling.

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Letter From a Master Plumber

I was in business for myself as plumber and tinner when I enrolled in the International Correspondence Schools. Now, as a result of your instruction, I get 100 per cent. more for my services than before I enrolled, and I have no fear of "getting stuck" on any job that I undertake—whether in steam, hot-water, or furnace heating, or plumbing. I cannot recommend the I. C. S. too highly to any one, young or old, who aspires to know his business thoroughly.

C. W. COLONY,
Sandy Creek, N. Y.

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PASSED STATE CIVIL SERVICE STEAM FITTERS' EXAMINATION

W. H. BAHN, 185 First St., Albany, N. Y., was foreman of a plumbing shop when he enrolled for the Complete Heating Course. What he learned from the Course enabled him to pass the civil service examination and subsequently to receive an appointment to the position of state steam fitter, at the Capitol Building, Albany, with a salary of $1,000 a year.

APPRENTICE BECOMES SUPERINTENDENT

ROBERT J. WALKER, JR., 2149 E. York St., Philadelphia, Pa., proves the truth of our claim that a better position can be had by the man that prepares for it. Through the I. C. S. Course he advanced from an ordinary apprenticeship to superintendent and draftsman, in hot-water construction, heating, ventilation, and fire-sprinkler work, at a salary of $1,200 a year.

PROMOTION COMES TO THOSE THAT STUDY

C. A. O. MAULE, Germantown, Pa., has demonstrated the value of a technical education. Since finishing his Course in Heating he was promoted to the position of assistant superintendent of the Germantown Steam Company.

NOW MANAGER OF A FUEL COMPANY

J. F. HARMON, 1620 S. Gal. St., Marion, Ind., knew nothing but a few of the first principles of the heating business when he took the I. C. S. Course. Now he is considered one of the best read and most practical heating men in Marion. An architect in that town, Mr. French, often has called on Mr. Harmon to assist in planning the heating arrangements of buildings.

LABORER NOW A PARTNER

G. W. PICKERING, Susquehanna, Pa., enrolled in the Sanitary Plumbing, Heating, and Ventilation Course while he was a laborer. He says the Course has been a great help to him. As a result of this he now is in partnership with another plumber and steam fitter. They installed the plumbing in the new post-office building in Susquehanna.

SALARY INCREASED THROUGH I. C. S. COURSE

JOHN J. BROM, Wimbledon, N. Dak., enrolled for the Sanitary Plumbing, Heating, and Ventilation Course and soon had his salary increased $15 a month. He now can figure and lay out different kinds o trade work.

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What Our Students Think of Us

My Course with the I. C. S. has served me well. It has taught me industry, concentration, and self-confidence. It has broadened my mind and created ambition to do larger things. It has given me self-reliance to do them. It has taught me to concentrate my mind on one thing whereby I can make a success. My intellect is benefited. The spirit of manliness is taught by your methods. I am well satisfied with my Course. The Schools are, to me, the greatest educational and instructive institution in the world and I would not part with my Course for double the price. The methods of instruction are so simple that if the student will apply a little concentration he will surely succeed in qualifying for higher honors. You do not know how appreciative I feel in regard to the Schools, and when my aid can be given to help them I only need notice to that effect.

J. J. JONES,
Richmond, Va.

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FROM $7 A WEEK TO $3.50 A DAY

DAVID CRAFT, 1406 Park Ave., New York City, was a plumber's helper, making $7 a week, when he enrolled in the Sanitary Plumbing and Gas-Fitting Course. Now he is a plumber in New York City, making $3.50 a day. He says the Course was a great aid to him in securing the license, as well as in many other ways.

BECAME A SALESMAN OF PLUMBERS' SUPPLIES

HERBERT R. LEAF, 932 Westminister St., St. Paul, Minn., was not working when he enrolled for the Sanitary Plumbing, Heating, and Ventilation Course. But he soon got a job, and was successful in selling plumbers' supplies. The Course is of great benefit to him in enabling him to talk intelligently to plumbers and heaters.

FROM $3 A WEEK TO $4 A DAY

B. P. LA BRANCHE, Capital St., Jackson, Miss., was a plumber's apprentice when he enrolled in the Plumbing and Gas-Fitting Course. He finished this Course and enrolled for the Heating and Ventilation Course. Besides receiving a good education in reading and writing English, which he did not have before corresponding with the I. C. S., he is making $4 a day. Mr. La Branche heartily recommends the I. C. S.

SALESMAN BECOMES MANAGER

J. HARRY BACON, 331 Genesee Ave., Cleveland, Ohio, learned the office end of the plumbing-supply business by hard experience. He then traveled as salesman for a time, soon taking up the Heating and Ventilation Course. As a result of his studies he has charge of the heating department of the Kennedy Company in that city.

SALARY INCREASED FIVE TIMES

JAMES F. COSTELLO, 297 Dublin St., Waterbury, Conn., was trying to learn plumbing by experience only, but found it too hard because the men he worked with had not time to teach him the theory of the business. He enrolled for the Sanitary Plumbing, Heating, and Ventilation Course. Soon his employer, Mr. D. J. Clancy, increased Mr. Costello's salary voluntarily. This happened four more times. Mr. Costello knows it pays to study in the I. C. S.

I. C. S. STUDENTS OBTAIN PLUMBERS' LICENSES

MICHAEL L. SYLVIA, New Bedford, Mass., took the Complete Plumbing and Heating Course and, by means of the information obtained from the Course, passed an examination and received a first-class master-plumber's license. He soon was making more money, at more congenial work, than before he had a technical education.

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Appointed Plumbing Inspector of Manila

Before becoming a student in your Schools I had only a common-school education and I was very rusty; beyond my practical experience I knew nothing. As soon as I enrolled I went right to work and as a result of the Course I entered a competitive examination (the first of its kind held in Manila) for Plumbing Inspector, a position paying $1.800 a year with a salary of $1,600 a year for an assistant.

The civil service examination in this line is thought to be a rigid one; I hardly believed that I stood any chance for the Inspectorship, but hoped I might come out second.

There were three competitors, and the examination lasted one and one-half days. When the time came to give out the result I was greatly surprised to learn that I was the only one that passed. As a result, I am today, and have been for the last two months, Plumbing Inspector for the city of Manila.

JOSHUA T. COLVIN,
Plumbing Inspector,
City of Manila, P. I.

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APPRENTICE BECOMES PARTNER

NELS P. BROOD, 121 Chestnut St., Princeton, Ill., was working as a plumber's apprentice when he enrolled in the I. C. S. He now is partner in a plumbing business, having gone into partnership with his former employer. Mr. Brood thinks the I. C. S. are the best schools in existence.

FROM $1.50 A DAY TO $80 A MONTH

B. J. BARDWELL, Sturgeon Bay, Wis., a tinner, getting $1.50 a day, enrolled in the Complete Plumbing and Heating Course and, as a result of his studies, now has full charge of the heating and plumbing department of the J S. Hay Hardware Company, at a salary of $80 a month. He will be glad to answer any inquiries regarding the Schools and the Course.

SALARY INCREASED 60 PER CENT.

W. SCOTT ARTHUR, Woodstown, N. J., enrolled for the Complete Plumbing and Heating Course. As a result of the instruction received he was promoted from journeyman plumber and tinner to foreman in charge of shop and construction work. His salary was increased 60 per cent. When Mr. Arthur enrolled he knew hardly any mathematics. Now he can undertake any difficult system of plumbing and heating. He says: "The I. C. S. is a successful salary medium."

APPRENTICE BECOMES CONTRACTOR

L. O. PAPIN, 469 Main St., Dubuque, Iowa, enrolled for a Course of instruction in Plumbing while an apprentice. He was promoted until he became foreman. By studying in advance of work he had to do, his experience as foreman was not only successful but valuable. Now he is in the plumbing and heating business for himself and gives the credit of his success to the I. C. S.

BECAME MASTER PLUMBER

WM. L. POLLOCK, 2583 Pitker Ave., Brooklyn, N. Y., was a junior plumber, making $2.50 a day, when he took the I. C. S. Course in Plumbing. Now he is a master plumber, in business for himself. He makes $4.75 a day.

NOW IN BUSINESS FOR HIMSELF

DANIEL S. LOWE, 1418-20 N. Sixth St., Harrisburg, Pa., began studying the Sheet-Metal Pattern Drafting Course by working as a tinner and obliged to depend on others to cut patterns for his work. As a direct result of what Mr. Lowe learned he now has a successful business of his own that pays him much better than working for others.

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WAGES INCREASED 24 PER CENT.

LOUIS J. GRAFF, 83 Curtin Ave., Pittsburg, Pa., enrolled in the Sheet-Metal Pattern Drafting Course while employed on all kinds of building work, such as tin roofing, lining gutters, erecting cornices, skylights, etc. What he learned from the Course enabled him to take a position in the best line of bench work, with an increase in wages of 24 per cent.

HELPER BECOMES PATTERNCUTTER AND PART OWNER

R. E. WILLIS, 2129 Seventh Ave., Moline, Ill., rose from the position of helper in a tin shop to that of patterncutter in a large sheet-metal concern. Besides being a stockholder and entitled to a percentage of the profits, his earnings have increased 100 per cent.

SHORTER HOURS AND BETTER PAY

C. V. STANLEY, 337 Union Ave., Laconia, N. H., enrolled in the I. C. S. when he was working from 10 to 14 hours a day and earning only $10 a week. Now he is employed by W. D. Huse & Sons, gets a better salary, and works 9 hours a day. He also is on the city plumbers' examining board.

FROM JOURNEYMAN TO QUARTERMAN

M. H. CILLEY, 510 Virginia Ave., Vallejo, Cal., was in the United States Navy Yard as a journeyman sheet-metal worker when he enrolled in the Sanitary Plumbing, Heating, and Ventilation Course. Before he finished the Course he was promoted to leading man sheet-metal worker with wages increased 25 cents a day. Realizing the value of technical knowledge, he enrolled for the Sheet-Metal Pattern Drafting Course and was promoted to quarterman sheet-metal worker with an increase in wages of 50 cents a day.

SALARY INCREASED $20 A MONTH

J. G. SMITH, 431 W. Boone St., Belvidere, Ill., was a tinner's helper and general roustabout when he enrolled in the Sheet-Metal Pattern Drafting Course. By studying the Course evenings he learned to develop patterns for any object. His wages were increased 75 cents a day and his prospects are very bright.

DOUBLED HIS SALARY

Since enrolling as a student of our Complete Plumbing and Heating Course, MR. CHARLES R. FROST, of Owen Sound, Ont., has been promoted in position, and today receives double the wages he was paid when he began his studies under our direction.

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JOURNEYMAN BECOMES PLUMBING INSPECTOR

When M. M. O'CONNELL, care City Hall, Chicago, Ill., began the study of our Complete Plumbing and Heating Course he was a journeyman plumber, working for the usual wages. Today, as a direct result of our instruction, he occupies a position as plumbing inspector, at largely increased wages.

PLUMBING INSPECTOR OF MANILA

JOSHUA T. COLVIN, of Manila, P. I., was working as an ordinary plumber two or three years ago. In a competitive examination for the position of Plumbing Inspector of the city of Manila, P. I., he was the only one who passed with the required percentage. As a result, he occupies a position that pays him a salary of $1,800 a year, with an allowance of $1,600 for an assistant.

IS NOW FOREMAN AT LARGELY INCREASED WAGES

JAMES A. BLACKNEY, of Ishpeming, Mich., was an ordinary journeyman, working for the usual wages, at the time he began the study of our Course. Soon he became a foreman at an increase in salary of 50 per cent., or one-half.

NOW EARNS $200 A MONTH

ARTHUR ELLIOTT, South Street, St. Paul, Minn., was foreman of a box factory when he began his Course in the I. C. S. He had a smattering of all kinds of knowledge in the building line but really could not work out simple problems. Now he makes excellent architectural plans, recently having won a competition for a new High School building. His earnings average $200 a month.

DRAFTSMAN AND ESTIMATOR

A. D. PAINE, Alabama Lumber and Shingle Co., Memphis, Tenn., has demonstrated the results following a Course of study in the I. C. S. Mr. Paine enrolled for the Architectural Drawing Course, which has enabled him to successfully compete with the best architects and contractors in his state. He now holds the position of draftsman and estimator for one of the largest concerns in Memphis, at more than double his former income.

SALARY INCREASED 200 PER CENT.

CHARLES S. FINNEY, 623 Temperance St., St. Paul, Minn., became draftsman for the St. Paul Furniture Company by means of the knowledge gained from his Course in the I. C. S. His income is 200 per cent. greater than it was when he enrolled.

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A University Graduate's Opinion

When I enrolled with the I. C. S., I was a postgraduate student at Columbia University. At present I am treasurer and general superintendent of the M. W. Hill Company.

I am a graduate in mechanical engineering, University of Pennsylvania, 1904; postgraduate in electricity, University of Pennsylvania; Licensed Stationary Steam Engineer, 1st grade, in Baltimore, Md.; Member of American Society of Heating and Ventilating Engineers.

The I. C. S. Course has been a great help in teaching me the "why" of things, also the "how" to do them.

NORMAN HILL,
1503 Sansom St.,
Philadelphia, Pa.

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